GIS BASED APPROACH TO ECONOMIC ASSESSMENT OF RESIDENTIAL FLOOD DAMAGE AT PROPERTY LEVEL

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Declaration

I certify that except where due acknowledgement has been made, the work is that of the author alone; the work has not been submitted previously, in whole or in part, to qualify for any other academic award; the content of the thesis is the result of work which has been carried out since the official commencement date of the approved research program; any editorial work, paid or unpaid, carried out by a third party is acknowledged; and, ethics procedures and guidelines have been followed.

Khan Kamruzzaman

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List of acronyms

AAD	Average Annual Damage
ABS	Australian Bureau of Statistics
AHD	Australian Height Datum
BTE	Bureau of Transport Economics
BOM	Bureau of Meteorology
CBD	Central Business District
DEM	Digital Elevation Model
EMA	Emergency Management Australia
ESRI	Environmental Systems Research Institute
FEMA	Federal Emergency Management Agency
FIT	Flood Information Tool
GB	Gigabyte
GIS	Geographic Information System
GNAF	Geocoded National Address File
MW	Melbourne Water
NHRC	Natural Hazards Research Centre
NIBS	National Institute of Building Sciences
NRE	Natural Resources and Environment
RAM	Rapid Appraisal Method
UK	United Kingdom
USGS	United States Geological Survey
USA	United States of America
VGV	Valuer-General Victoria

Abstract

Flood is one of the major natural disasters in Australia. It breaks down transportation and communication systems, disrupts businesses and causes damage to properties, loss of stock, crops and also loss of human lives. Better understanding of the impacts resulting from floods and other natural hazards can help to reduce the damages or losses. Flood damage assessment procedures estimate the impact of flood in monetary terms to help decision makers develop new policies, programs and development plans.

This study examines different techniques, procedures and underpinning philosophies that have been used in some major emergency management and insurance organizations in the world such as RAM, ANUFLOOD, and HAZUS and NHRC. From this examination the study finds that none of them are suitable for mitigation and emergency purposes in producing economic flood damage estimation at fine resolution with high accuracy. From this perspective the study develops a rigorous procedure for property level economic flood damage assessment. The assessment procedures are embedded within GIS (Geographic Information System) technology which can model and analyse the multidimensional phenomenon of flood and damage characteristics of residential buildings.

The damage estimation procedures developed in this study include flood modelling, collection and organisation of building inventory data; adopting a set of stage-damage curves; and measuring damage at property level. The quality of damage estimates derived from the procedures is highly influenced by quality of input data. The study also includes the implementation of the damage assessment procedure on the study area (a segment of Kororoit Creek and its adjacent area). The study uses data from a number of sources including Melbourne Water, NEXIS, VICMAP, a quick survey and literature.

The developed procedure will help many practitioners in flood loss assessment and natural hazard risk management to face the challenges they have in establishing damage estimates with high accuracy.

CHAPTER 1:

INTRODUCTION

1.1 INTRODUCTION

Occurrences of natural disaster are increasing across the world due to a number of factors such as changing climate and increasing population in vulnerable areas. Better reporting of natural disasters in recent years (Chapman 1999) has increased the visibility of their impacts. Natural disasters break down transportation and communication systems, disrupt businesses and cause damage to properties, stock, crops and cause loss of human lives. Since 1967, floods alone in Australia have resulted in a total cost of $10 billion and an annual cost of about $315 million (BTE 2006). Moreover, it is inevitable that more natural disasters will occur in the future and our environment and community will be more vulnerable which will ultimately increase the cost. To minimize the cost of floods or any other natural disasters, a better understanding of the impacts resulting from them is required (Granger *et al.* 1999). Flood damage assessment procedure estimates the impact of flood in monetary value. It helps decision makers develop new policies, programs and development plans.

Existing flood damage assessment models in Australia such as RAM, NHRC and ANUFLOOD are not suitable for mitigation and emergency purposes in producing an economic flood damage estimation at fine resolution with high accuracy (EMA 1997). The existing models either produce gross estimation which is reasonable at coarse resolution, or produce estimation for insurance purposes, or are outdated. From this perspective, the study intends to develop a rigorous procedure for property level economic flood damage assessment. The procedure includes modelling flood level to estimate flood depth at property level; collecting and organizing data of building characteristics; adopting a set of stage-damage curves, (more discussion on stage-damage curves will be given in sections 3.5, 4.4 and 6.6), and measuring damage at property level. The procedure developed in the study can be used to generate highly accurate damage estimates based upon highly accurate input data, such as flood data, building inventory data and stage-damage curves. The procedure is demonstrated with a case study using data from a number of sources.

The study suggests the development of a consistent nation-wide multi-hazard methodology based on GIS technology to help catchment authorities, emergency management authorities, mitigation authorities, insurance companies and all others related to risk management to make decisions in support of sustainable and safe community development. Without a rigorous and consistent process of assessing flood damage, decision makers at all levels would not have information upon which they can make prudent decisions to mitigate the effects of future floods.

1.2 RESEARCH OBJECTIVE

The overall objective of the study is to develop a GIS based procedure for economic assessment of residential flood damage at property level. To meet the research objective, a number of research questions need to be answered. They are as follows:

- How can flood depth be modelled using GIS for effective assessment of residential flood damage at property level and what kind of data are required for this type of flood depth modelling?
- What kind of building inventory data is needed and how can these data sets be collected and organised into GIS datasets to support effective assessment?
- What kind of stage-damage curves are required and how can applicable stage-damage curves be collected and adopted for the GIS based assessment?
- How can residential flood damage be measured?

1.3 RATIONALE OF THE RESEARCH STUDY

As discussed in Section 1.1, floods cause significant damage to assets and stock worth billions of dollars and the loss of human lives in Australia. To minimize the cost of floods, a better understanding of the impact from them is required. A better understanding can help to make better predictions, which could ultimately reduce the costs from future floods. Note that when impacts of any flood disaster are assessed in monetary value they are called cost (Gissing and Blong 2001). Quality of damage estimations enhances better understanding of flood impacts. For this reason the study aims to develop a GIS based flood damage assessment procedure of residential buildings at property level. The rationale for the study is discussed in detail below.

Firstly, natural disasters, including floods and their impact, vary between places and times due to a range of factors. These include when, where and how the hazard event happened, and the spatial-temporal variations of site characteristics which result from both natural processes and human activities. Their impact can not be comparable directly between places and years, even for impacts resulting from events of the same type and magnitude (National Research Council 1999). For example, a flood which extends over both rural and urban areas with the same magnitude can damage 3000 hectares of cropland and 50 residential buildings. These damages can not be compared to each other directly unless they are converted into monetary values. Similarly, two floods having similar magnitude in two different years acting on the same residential area or even the same set of existing residential buildings may cause different levels of damage. The reason for this may be that some new buildings have been built in that area or that the structure and contents value of the existing buildings has changed. Flood damage assessment processes convert all impacts into a monetary value and follow economic principles and theories in order to integrate economic, social and environmental impacts into facts and figures (EMA 1997). Therefore, flood damage assessment is conducted in such a manner that will enable effective comparisons between the impact of flood between places and over a number of years and help decision makers to prioritise mitigation initiatives and measures accordingly (Granger *et al.* 1999).

Secondly, insurance policy makers or managers need suitable flood damage estimation procedures to assess the vulnerability of properties lying in a floodplain. The assessment of vulnerability helps to determine the premium payable on the properties. After a flood event, flood damage estimation procedures are also needed by policy makers or managers to estimate the building replacement cost of damaged properties which are insured. Though this study is more oriented towards mitigation purposes, it can serve insurance purposes by modifying a few aspects of the procedures developed by the study.

Thirdly, flood damage assessment results usually include Average Annual Damage (AAD) to indicate the average damages from a number of floods at a specified location. AAD considers not only the damages but also the benefits that result from different management strategies or mitigation initiatives which are in place. Therefore a measure of the cost benefit ratio of any flood event with the strategies and initiatives taken for it is able to be done (Middleman and Granger 2000). This also helps decision makers set priorities between locations – in which case consistency of approach and avoidance of bias in assessment are important (Thompson and Handmer 1996). Although the study does not calculate AAD, it does set out a clear framework of how the AAD can be incorporated into further studies.

Finally, the study follows procedures which can produce better quality damage estimates than with commonly used methods in Australia. A number of flood damage assessment methods have been used in Australia. However, none of them is suitable for assessing residential building damages at a fine resolution. For example, the Rapid Appraisal Method (RAM), one of the popular models used in Australia, estimates average damages at $20,500 AU for each flood affected residential building. RAM estimation is more suitable when estimating the total damages of thousands of buildings (Reed Sturgess and Associates 2000). However, the average estimation of RAM may produce ambiguous results when only a few houses are damaged or the study area is small. Moreover, the procedure deployed by this study embeds GIS technology. This is regarded as a particularly suitable tool for modelling natural hazards including floods. GIS enhances modelling and understanding of floods and their impacts on residential buildings. Therefore, the flood damage assessment procedure presented in this study generates a better quality of damage estimate than that derived from RAM or any other Australian model.

1.4 SCOPE OF THE STUDY

Components of flood that cause flood damage include its depth, velocity, duration and load (Figure 1.1). Among these flood components, depth is the most responsible for causing damage and it is a compulsory element in any damage assessment procedure. This study only includes flood depth in flood modelling for the deployed flood damage assessment procedure. However, the procedure deployed in this study can provide options to include other flood components for further studies. The scope of this study is shown in Figure 1.1.

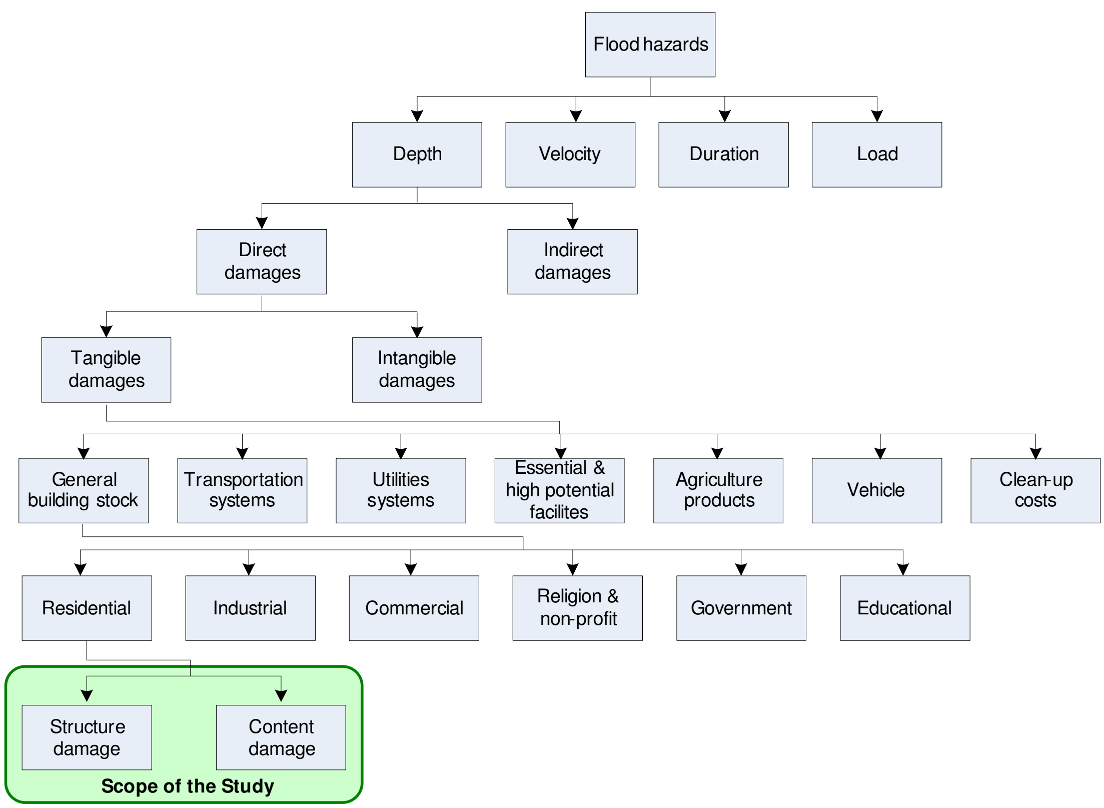

Figure 1-1: Schematic diagram showing Scope of the study

Damage from floods, as shown in Figure 1.1, can be classified into three major categories: direct damage, indirect damage and intangible damage. Direct damage results from direct physical contact of floods. Indirect and intangible damage are not discussed in this thesis as they are not included in the study scope. However, Section 3.2 defines each of them in detail and discusses how they are induced from floods. Direct flood damage or cost can be classified in seven sectors: 1) general building stock, 2) transportation system, 3) utilities system, 4) essential and high potential facilities, 5) agricultural products, 6) vehicles and 7) clean-up cost. The general building stock is further classified into six sub-categories, according to their use, including: 1) residential, 2) industrial, 3) commercial, 4) religion and non-profit, 5) government and 6) educational. This study focuses on residential buildings and does not deal with any other buildings or any other direct, indirect and intangible features in its damage assessment. The assessment of residential building damage includes structural damage and contents damage.

1.5 METHOD TO BE USED

The objective of the study is to develop a GIS based procedure for assessing residential flood damage at property level. To achieve this objective, a GIS based approach to economic assessment of residential flood damage at property level has been developed in this study, based on literature reviews, expert consultations and brainstorming sessions with different experts.

The thesis has been organised into 7 chapters, each linked to their respective research tasks to answer the identified research questions. Figure 1.2 shows the methodological process of flood damage assessment procedures deployed in the study.

Step1:

In Chapter 2, a brief discussion on floods and their physical processes is carried out to lay down the necessary theoretical foundation for building a flood model used in the damage assessment procedures. Key points discussed in the chapter include:

- definition of floods and their classification;
- concept of flood intensity factor and flood hydrograph;
- concept of floods as a hazard;
- major floods in Australia and their impacts.

Step 2:

Chapter 3 focuses on the theoretical aspects of flood damage and the assessment procedures which are needed in damage assessment procedures. Key points covered in the chapter include:

- concept of flood damage and their components;
- concept of stage-damage curves and AAD;
- concept of flood damage assessment;

- review of some flood damage assessment models.

Step 3:

Chapter 4 presents the framework of analytical procedures used in the study, including a brief description of each step involved in the analytical procedures. More detailed discussions of these steps will be provided in chapter 6. Key issues addressed in the chapter include:

- flood depth modelling;
- building inventory data organisation;
- stage-damage curves and their adoption;
- measuring flood damage;
- result validation.

Step 4:

Chapter 5 discusses different aspects of the study area related to the damage assessment procedure, including:

- location of the study area;
- its land-use, settlement history, demography and geomorphology;
- its history of flood.

Step 5:

Chapter 6 presents in detail the analytical procedures discussed in chapter 4. The discussion of the analytical procedures includes their implementation in the study area by means of tables, graphs and maps. Key points noted in Chapter 6 include:

- data collection;
- mapping flood surface;
- building inventory;
- adopting stage-damage curves;
- measuring damage;
- validation of the result derived from developed procedures.

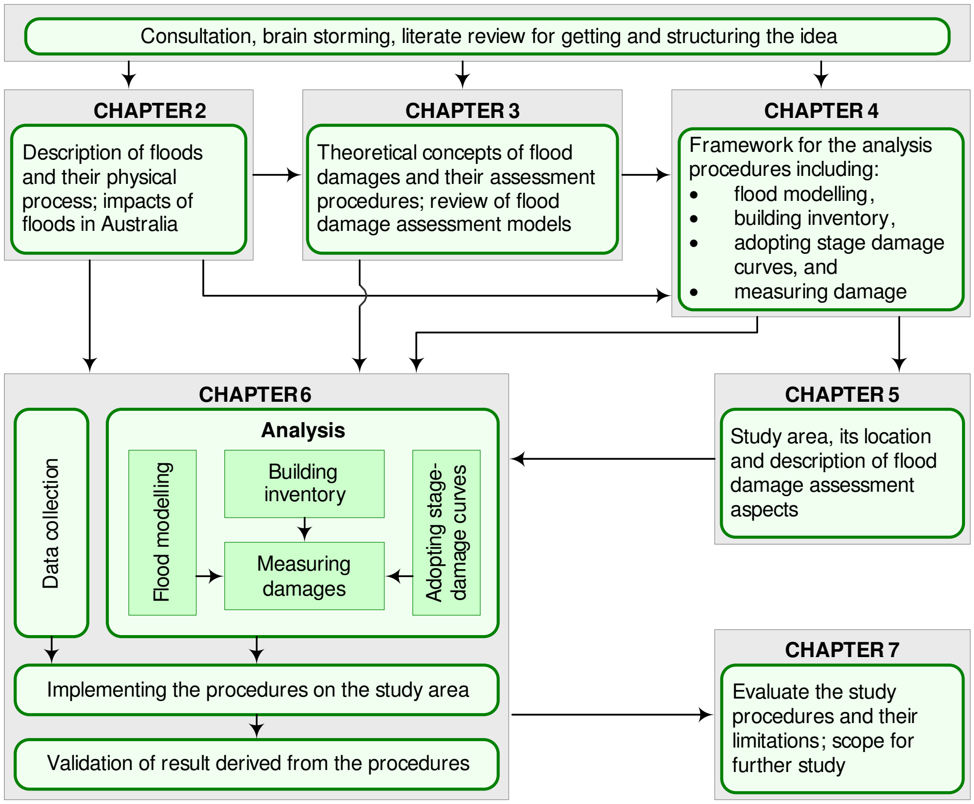

Figure 1-3: The methodological process of flood damage assessment deployed in the study.

1.6 CONCLUSION

This chapter has outlined the objectives, rationale, scope and methodology for establishing a GIS based procedure for economic assessment of residential flood damage at property level. The research questions identified in this chapter will be answered in the following chapters.

The next chapter establishes the theoretical framework of the concept of floods and their physical processes and impacts in Australia.

CHAPTER 2:

FLOODS, THEIR PHYSICAL PROCESSES AND IMPACTS IN AUSTRALIA

2.1 INTRODUCTION

In Australia, flood is considered to be the most expensive natural hazard in the last few decades (EMA 1997). Flood damage assessment methods evaluate the impact of floods in monetary value that are eventually used in planning and decision making processes. Therefore, a consistent and vigorous approach for flood damage assessment is obligatory for all level of stakeholders. The aim of the study is to find out which kind of approach suits the Australian context considering all circumstances; for example: geographic and physical conditions, socio-economic conditions and data availability.

Before assessment of flood damage can begin it is necessary to understand floods and their characteristics clearly. For this reason this chapter concentrates on establishing the meaning of terms and concepts of floods and their physical processes as they are used throughout this thesis. Firstly, this chapter illustrates the definition of floods, their classifications and commonly observed floods in Australia. This is followed by the discussion of physical processes of floods such as Flood Intensity Factors, Flood Hydrograph, Flood Estimation and Flood as Hazard.

2.2 DEFINITION OF FLOODS

It is difficult to define floods because they are complex phenomena and are viewed differently for different purposes. For the purpose of this study, floods can be defined as follows:

“Floods are relatively high stream flow that overtops the stream banks in any part of its course, covering land that is not normally under water” as it is defined in Glossary of Hydrology (1992).

In order to incorporate coastal floods, the more appropriate definition was given by Ward (1978),

“Floods are body of water which rise to overflow lands which are not normally submerged”.

These definitions explicitly include surface inundation. However, cities which have complex underground transport networks and services may have subsurface flooding due to rising underground water levels (Smith, 1998). However, since this study does not consider the damage due to such subsurface flooding, the above definitions cover the scope of this study.

2.3 CLASSIFICATION OF FLOODS

Floods are usually classified on the basis of their causes. They are broadly classified into two categories, riverine and coastal, which are described below.

2.3.1 Riverine floods

"The floods which occur in river valleys on the floodplains or wash lands as a result of flow exceeding the capacity of stream channels and overspilling the natural banks or artificial embankments" are called riverine floods (Smith, 1998, pp 10).

Most of the causes of riverine floods are climatological in nature as shown in Figure 2.1. Among them, excessively heavy and/or excessively prolonged rainfall is the most common cause of floods around the world. In addition, in cold countries, substantial riverine flooding occurs during the period of snow-melt or ice-melt in spring or early summer, particularly when melting rates are high (Ward, 1978). Sometimes, rain on snow or ice increases the melting rate, and the combination of rain-water and melted-ice water causes extensive flooding in a river catchment area. Sudden collapse of ice-jams also causes flooding in cold areas. A violent riverine flood could result from the collapse of a dam, and can cause considerable damage to lives and properties (Walter, 1971).

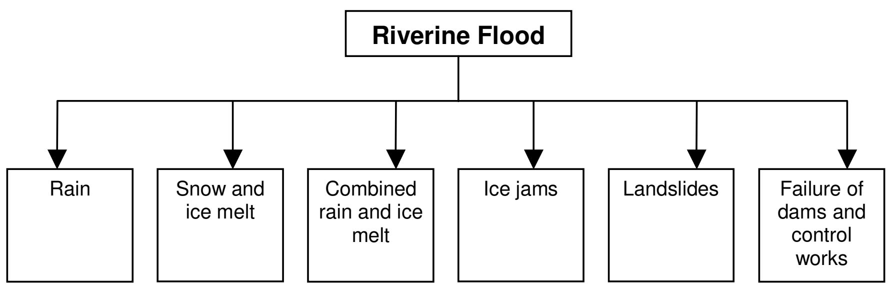

Figure 2.1: Causes of Floods
Source: Ward (1978)

In addition to the causes illustrated above, urban areas may also be flooded due to overspilling of stormwater drains (Murray, 1995). Riverine floods can be classified into four sub categories which are described below.

2.3.1.1 Flash floods

Floods which occur for a short duration with a relatively high peak of water flow are called flash floods. Usually these are violent and result from rainfall of high intensity over a small area (IAHS, 1974). Flash floods are often measured in minutes rather than hours and common in urban areas having poor and inadequate drainage systems. The flash flood hydrographs (definition of flood hydrograph is set out in Section 2.7) normally have sharp peaks and the rising and falling of flood water are rapid as shown in Figure 2.2 (Ward, 1978).

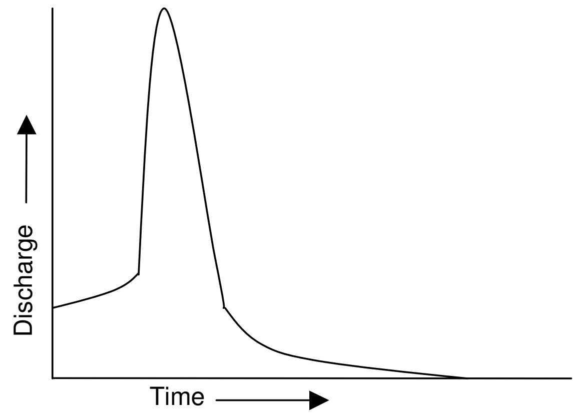

Figure 2.2: Hydrograph of a flash flood
Source: Ward (1978)

2.3.1.2 Single event floods

Single event floods are those which have a single main peak of water flow but last longer than flash floods. This is common in most parts of the world and can be the result of rainfall that last several hours or days (Ward, 1978).The single event flood hydrograph is shown in Figure 2.3.

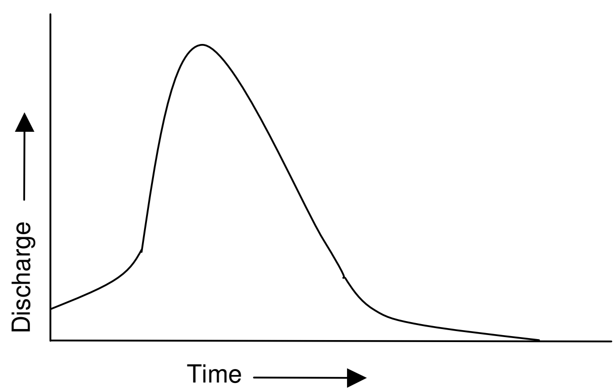

Figure 2.3: Hydrograph of a single event flood
Source: Ward (1978)

2.3.1.3 Multiple event floods

Multiple event floods are those which have several peaks of water-flow and are probably the most problematic form of flooding in the world. This kind of flooding is often severe because its duration extends over a period of several weeks or months (Ward, 1978). The hydrograph of multiple event flooding is shown in Figure 2.4.

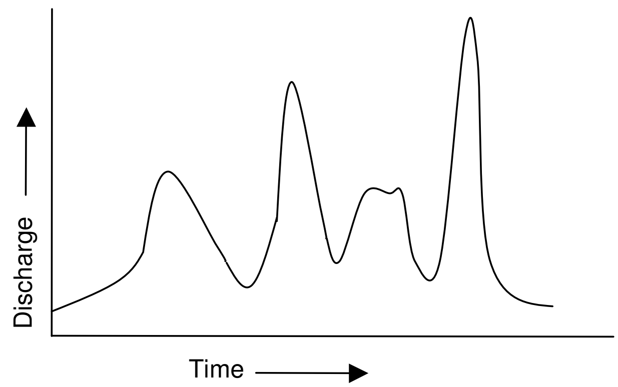

Figure 2.4: Hydrograph of a multiple event flood
Source: Ward (1978)

2.3.1.4 Seasonal floods

Seasonal floods are similar to multiple event floods. However, these return almost annually in the wet season on a massive scale. This kind of flood usually lasts several months and sometimes it is followed by drought (Rogers *et al*. 1989).

2.3.2 Coastal floods

Floods of saline water which occur in low lying coastal areas, including estuaries and deltas are called coastal floods. In estuaries, the interaction of fresh water flow from the river and saline water from the sea towards the land during high tidal fluctuations cause brackish water (brackish water is saltier than fresh water, but not as salty as sea water) floods. Furthermore, saline water from the sea inundating coastal areas because of exceptionally large wind-generated waves are called saline water floods (Smith and Ward 1998; Ward 1978).

Coastal floods usually result from extreme climatological events, such as storm surges, tsunamis and sea-level risings. Storm surges are the most common coastal flood around the world and occur as a result of low atmospheric pressure when wind speed increases the elevation of the sea's surface, especially when it coincides with high-tides. The shape of the coastline and near-shore sea bed, and the characteristics of the tides are some of the other major influential factors on the height of the surge and its potential for damage. For example, funnel shaped coastlines can increase the severity of coastal floods, such as in Bangladesh, where hundreds of thousands have drowned in coastal floods in the last few decades (Handmer 2004).

Tsunamis are another cause of coastal floods. These are triggered by submarine earthquakes, landslides, or volcanic eruptions. Similar effects can result from the explosion of nuclear bombs (Bascom 1959). The wavelength (that is distance between successive crests) is normally shorter than wind-generated waves, but their wave periods (that is interval times between successive crests) are very short, thus creating a marked increase in wave height. The 2004 Indian Ocean Tsunami inundated the coastal area of Indonesia with waves up to 30 metres high and killed about 22500 people in eleven countries (Mathew 2005).

Rising sea-level is another significant cause of coastal floods. Global warming increases the ice melt which consequently causes the sea-level to rise and causes coastal floods. Coastal flooding due to rising sea-levels is now a major global issue. It is predicted that in the near future, significant portions of the world will be inundated by sea water permanently (Petak and Atkisson 1982), and indeed this is already occurring.

2.4 FLOODS IN AUSTRALIA

In Australia, coastal floods are not as common and are not considered a severe natural hazard (Jones, Middelmann and Corby 2005). Most of the floods in Australia are riverine and are a result of excessive rainfall except the few that result from snow-melts (Smith and Handmer 2002). The types of riverine flood in Australia range from slow rise floods that may be predicted weeks in advance, to flash floods that may not even be able to be predicted few hours in advance (COAG 2002). The common types of floods in Australia are described below and their distribution is shown in Figure 2.5.

2.4.1 Slow onset floods

Slow onset floods usually occur on plain lands and in the distributor channel systems of central New South Wales and Queensland, as well as in some parts of Western Australia, and occur as a result of heavy rainfall. Limited capacity of the channels and extremely flat floodplains makes the flood widespread in this area. In this type of flood, the water rises slowly and stays longer than other type of flood. This flood can lead to major losses of livestock and damage to crops and sometimes it leads to extensive damage to rural towns, roads and transportation systems. The great flood in 1990 is an example of a slow onset flood in Australia which covered more than one million square kilometres of Queensland, New South Wales and smaller areas of Victoria (EMA 1997). The impacts of the Great Flood in 1990 are discussed in detail in Section 2.4.4.2.

2.4.2 Rapid onset floods

This kind of flood is more severe than other type in Australia and is commonly observed in northern New South Wales and southern Queensland. The flooding, as a result of heavy rainfall or tropical cyclone, occurs more quickly but the flood water lasts only a few days. It has more potential to damage properties and result in the loss of lives because there is usually only a short time frame for people to take preventative action (EMA 1997). The Brisbane Flood in 1974 is an example of rapid onset flood in Australia. The impacts of the Brisbane Flood in 1974 are discussed in detail in Section 2.4.4.1.

Another type of flood was observed in the Gulf of Carpentaria area of Queensland, the humid tropical regions of Northern Territory and north of Western Australia. It is similar to rapid onset flooding but it poses less economic consequents because there is limited development in this part of the continent (Devin and Purcell 1983).

2.4.3 Flash floods

In Australia this kind of flood results from relatively short and intensive rainfall, often from thunderstorms. It occurs in all most every part of Australia, and poses great threat to lives and significant property damage. Two major examples of flash floods are the Melbourne Flood and the Canberra Flood in 1971 (EMA 1997). Approximate locations of these two flash floods are shown in Figure 2.5.

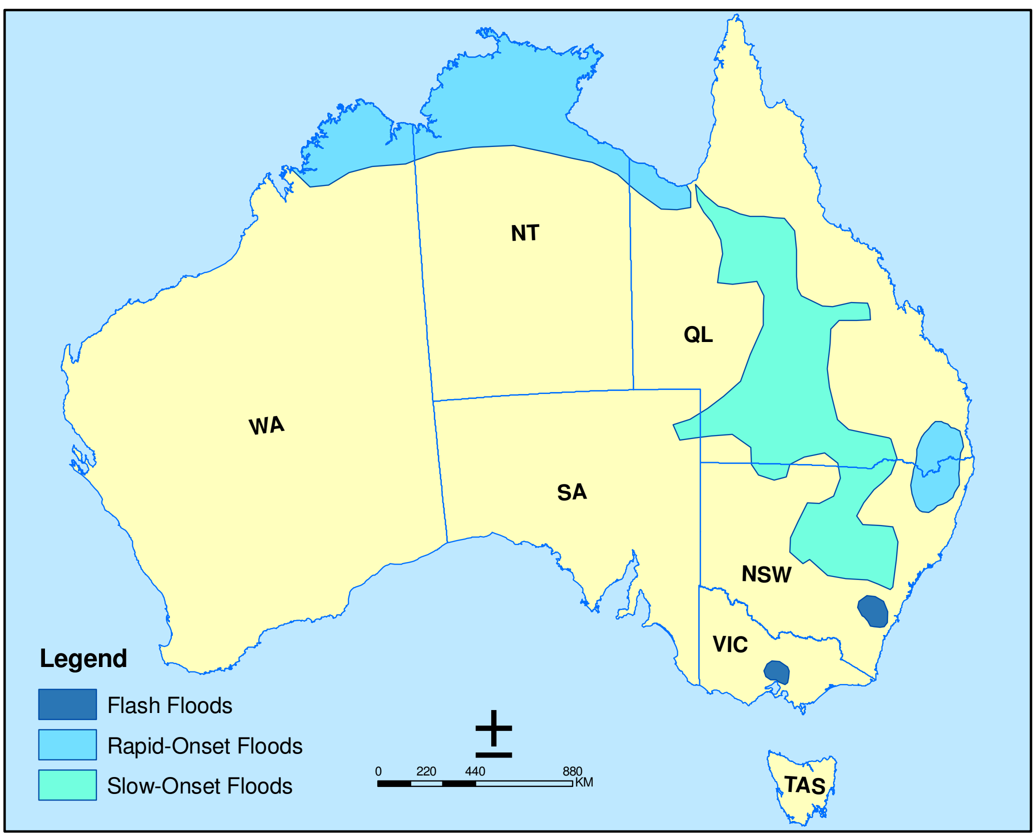

Figure 2.5: Approximate location of common floods in Australia.
(Information derived from EMA (1997); Devin and Purcell (1983))

2.4.4 Flood history in Australia

Flood is the most expensive natural disaster in Australia, costing on average $315 million per year (BTE 2001). Some of the recent severe floods and their impacts are described below.

2.4.4.1 Flood in 1973/1974

Between the end of 1973 and the beginning of 1974 was one of the wettest periods ever known in Australian history. The moist tropical air mass produced substantial rainfall over much of Queensland, some parts of New South Wales and Victoria, and most of the areas of these states were saturated before the beginning of 1974. As rainfall continued, it caused probably the biggest continent wide flooding since European settlement. In the first week of January 1974, northeast Victoria, parts of Riverina and Albury were flooded and northern New South Wales was flooded during the following week. Even Queensland with its extensive area of dry landmass became a vast inland sea. Huge amounts of cattle were lost as the monsoonal rain poured down. Railways and roads were cut and people were evacuated by helicopter (EMA 1997).

Furthermore, tropical cyclone 'Wanda' crossed the southern Queensland coast on the 24th January 1974, causing only minor wind damage but the associated rain depression contributed to heavy rainfall over the next five days. As a result, an extensive flood spread over Brisbane, as well as New South Wales and Victoria. 16 people died, 300 were injured, and 8,000 were homeless as 56 homes were swept away and 1,600 were almost submerged. The total insurance claim was $328 million (1997 value) and the total damage was $2200 million (1997 value) (EMA 1997 and BOM 2006).

2.4.4.2 Flood in 1990

The 1990 flood in Australia was as large as it covered more than one million square kilometres of Queensland, New South Wales and small area of Victoria. The flooded area was larger than the total area of Germany (EMA 1997).

Continual heavy rainfall and a cyclone over the period of a few weeks made central-north New South Wales and central-southern Queensland saturated with some associated flooding. Then further torrential rainfall on already saturated ground created almost instant floods. Road and rail links were broken for a long period of time in both states. Almost every building in Nyngan, New South Wales was flooded as the levee banks of the Bogan River were overwhelmed by flood water. 2,500 people were evacuated, mainly by helicopters, to Dubbo, 160 kilometres away.

Similar situations occurred in Charleville, Queensland where 80% of the population (about 3,000 people) were flooded and the entire town services were lost. Many people were forced to stay on their rooftops and had to be rescued by helicopters. About 2,000 residents were evacuated.

Torrential rains over Gippsland, Victoria also caused heavy flooding on the Thompson, Avon and Mitchell Rivers. People were evacuated from caravan parks and low-lying areas. About 150 homes were flooded, many hectares of vegetable crops were inundated and highways were cut.

Across the three affected states, the great floods of 1990 claimed 7 lives, injured 60 people, and rendered 5,000 temporarily homeless. The total estimated cost of these floods was $415 million (1997 value), and most properties were uninsured (EMA 1997; BOM 2006)

2.4.4.3 Floods in 1998

Two severe floods occurred in early January 1998 in two different locations. The first was a flash flood in Townsville, which started on January 10 and lasted for a few days. Tropical cyclone 'Sid' passing over Townsville caused landslides, wind damage and extensive rainfall (361 millimetres of rainfall in 6 days). As a result, all creeks in Townsville and surrounding regions were flooded within a few hours. Boats, cars, and even houses, were washed away. Water up to 3 metres deep passed through many parts of the city and caused heavy damage to businesses and public utilities. More than 20,000 residents in Townsville were without electricity and clean water for several days due to the breakdown of the power grid supply and the collapse of sewerage pumping stations. In terms of city highways, most of the roads and rail links were cut by flood water. The Townsville airport was also closed due to flooded runways and damaged navigation equipment. Across all affected regions, over 6,000 buildings were damaged, 250 people were evacuated, 2 people were killed and about 50,000 people were affected. The total estimated cost was about $69 million (1998 value) (EMA 1997; BOM 2006).

The second flood occurred on January 26, 1998, just after tropical cyclone 'Les' passed through Katherine, Northern Territory. The cyclone brought heavy rainfall (about 450 millimetres in two days), which drenched significant areas of the Katherine, Roper and Daly river catchments. The areas were already saturated from rains earlier in the month; therefore, this additional rainfall resulted in dramatic impacts. By the 27th, Katherine was inundated. Most of the roads were covered by 2 metres of muddy water. Electronic communications were cut. 1,200 houses and apartments (60% of total residential units) and about 500 businesses in the CBD (central business district) of Katherine were flooded.

Many cars were washed away or submerged. In this flood, 5,000 people were evacuated, 3,600 people were homeless, 8,500 people were affected and at least 3 people died. The total insurance cost was $70 million (1998 value).

2.5 FLOOD INTENSITY FACTORS

The intensity of coastal floods is largely influenced by the shape of the coastline. For example, in Bangladesh, when sea level rises in the wet season, the sea water level increases rapidly in the narrower sections because of the funnel shape of coastal line (Islam 1997). This rapid increase in sea level causes heavy flooding in the coastal areas. The gradient of the offshore seabed effects the intensity of coastal floods, and also the height of tsunami waves. Where there is a gradual slope of the offshore seabed, the tsunami waves are likely to be higher, causing more damage on the shore. On the other hand, coastal areas that have an offshore seabed with a steep slope tend to be less affected by tsunamis because steep slopes render waves smaller in comparison to a gradual slope (Smith and Ward 1998; Ward 1978).

River floods are usually intensified by catchment characteristics, drainage network and channel factors. Most of them influence the speed of water movement in the catchment. For example, a larger catchment produces larger amounts of rain water which may cause larger flooding. Basin shapes and patterns of drainage networks can influence the size and shape of the floods (Smith and Ward 1998; Ward 1978).

In addition, hydrological variables such as water storage, infiltration and transmissibility also influence the intensity of flooding (Smith and Ward 1998; Ward 1978).

Water storage in soil and subsurface layers often effects the time and magnitude of flooding in response to the process of precipitation. Low water storage capacity in the soil and subsurface layers means that only minimal water can be absorbed so that rapid and intense flooding can result. On the other hand, high water storage capacity in soil and subsurface layer causes slow and minimal flooding because the soil and subsurface layer can absorb more water.

The infiltration process in the soil moves excess water from precipitation into subsurface layers and discourages over-surface water movements. This ultimately influences the magnitude of flooding. For example, soil having a low capacity for infiltration can not absorb excess water quickly and encourages over-surface water movements. It increases rapid water flow in the channel and leads to an increase in the flood magnitude.

Transmissibility is the ability of the subsurface to let water pass through it and is basically determined by subsurface materials. The rate of infiltration depends on the rate of transmissibility which ultimately influences the magnitude of flooding.

These hydrological variables are often influenced directly by human activities like urbanisation, agriculture, forestry, and dam construction. Therefore, these and many other types of human activities also influence flood intensity (Smith and Ward 1998).

The aim of the study is to devise a better tool for the assessment of flood damage. The magnitude of flood damage is directly related to the severity of the flood, which in turn depends upon the flood intensity factors. Better understanding of the concepts and physical processes of flood intensity factors is indispensable for a competent assessment of flood impacts.

2.6 FLOOD HYDROGRAPH

According to the Glossary of Hydrology (1992), a graph which shows the discharge, depth, velocity or other properties of water flow with respect to time for a given point on a stream is called a hydrograph. There is no basic difference between a hydrograph and a flood hydrograph; a Flood Hydrograph represents the flood flow instead of normal stream flow (Lo, 1992). A brief discussion of the flood hydrograph is given below.

In Figure 2.6, the decrease of stream flow in dry season is shown as AX. At this stage, the discharge only consists of the base-flow of the stream which is largely stable and is influenced by a number of variables including steepness of the riverbed, permeability of the catchments and volume of groundwater flow. Rainfall begins at time X and the discharge rapidly increases to its peak flow at time Y. The increase of discharge between X and Y is primarily due to extensive rainfall that adds extra water to the stream and decreased filtration rate of surface soil, and transmissibility rate of the sub-surface layers of the catchment soil. The peak of discharge occurs (Y) soon after the rainfall stops. The volume of discharge is determined largely by the capacity of storage in surface soil and subsurface layers in the catchment. The rate at which water storage capacity is exhausted determines the shape of the declining limb of the hydrograph (YB).

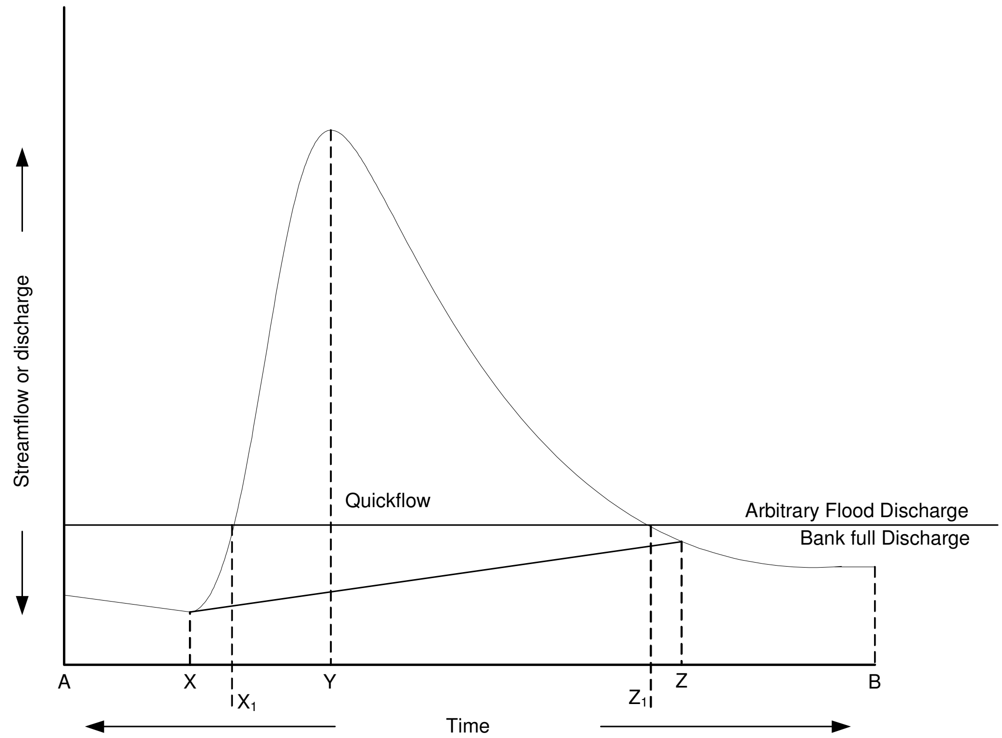

Figure 2.6: Flood Hydrograph in different periods
Source: Modified from Hoyt and Langbein (1955)

Figure 2.6 also illustrates that the flood hydrograph is dominated by a quick flow component, with a time based XZ and a peak Y. Usually, floods do not start immediately after increase of discharge at time X, because either channels are able to contain the extra water or increased water levels are still below the specified flood level (often the bank full discharge). The actual flood starts at X_1 and finishes at Z_1 as rising and falling limb intersect the pre-selected flood level respectively. The shape of the hydrograph may vary for different types of floods on the basis of their characteristics as discussed in Sections 2.3.1.1, 2.3.1.2 and 2.3.1.3 (Smith and Ward 1998; Ward 1978).

From the above discussion it is clear that an increase in the discharge of a river will not be considered to be flood until it has passed the predefined flood level. Catchment authorities usually define the flood level. This may be different between regions based on geographic variations. The flood level may also be varied within a region where there is infrastructure such as a dam which can discharge at a higher rate than a catchment without one. The flood hydrograph can be helpful for providing information about duration (start time and end time) and depth of floods. This information is required for any flood modelling and flood damage assessment.

2.7 FLOOD AS HAZARD

Natural hazards, including flood hazards, are extreme geophysical events which create unexpected threats to human lives and properties. An extreme physical event like a severe flood in a remote or unpopulated region that has no human activity may change the entire floodplain drastically but will not be considered a hazard. Thus flood risk or damage has negative economic and social consequences resulting from extreme natural events that affect human activities (Smith and Ward 1998). This risk can be inflated by different reckless human activities, such as unwise land use practices related to deforestation or urban development. On the contrary, this risk can also be reduced by prudent human activities, such as constructing well-planned flood control structures or developing effective emergency management plans (Green, Tunstall and Fordham 1991).

Therefore, flood hazard is defined as a combination of physical exposure and human vulnerability. Physical exposure refers to the type of flood event and their statistical pattern such as, a 100 year flood at a particular site. Human vulnerability refers to socio-economic factors such as the number of people at risk within the flood-plain or low-lying coastal zone.

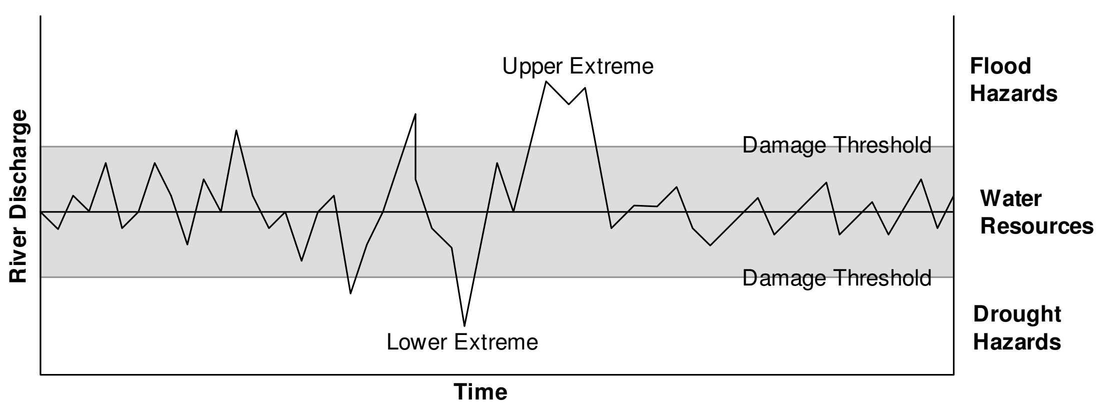

Figure 2.7: Flood hazards in relation to socio-economic tolerance
Source: Modified from Hewitt and Burton (1971)

In Figure 2.7, the variations of a river's discharge are plotted against time, and superimposed on the social and economic tolerance levels of the communities within the river catchment. This shows the relationship between discharge and tolerance levels. When the river-flow is within the tolerance levels, the discharge or river flow is not considered as a hazard but as water resource, because it is used for water supply, irrigation, water transportation and many other human welfare purposes. When the discharge exceeds the tolerance level, however, it is considered either as a flood hazard if the discharge exceeds the upper tolerance level or as a drought hazard if the discharge exceeds the lower tolerance level.

This study is only concerned with floods that are considered to be hazards that can cause damage or loss to human activities. The 100 year flood hazard of Kororoit Creek will be modelled in Section 6.3, and the potential damage to residential buildings caused from the flood hazard will be measured in Section 6.7.

2.8 CONCLUSION

The concepts and terminologies related to floods and their physical processes discussed in this chapter form a fundamental theoretical basis of this study and have been used throughout the thesis.

The next chapter concentrates on concepts and theories related to flood damage assessment, including types of flood damage, differences between economic and financial assessment, stage-damage curves, mechanism for flood damage and basic techniques and methodologies for flood damage assessment.

CHAPTER 3:

THEORETICAL ASPECTS OF FLOOD DAMAGE AND PROCEDURES FOR THEIR ASSESSMENT

3.1 INTRODUCTION

Concepts of floods and related physical processes discussed in chapter 2 provide a necessary knowledge base for the creation of a flood model. In this study, a flood model is used to estimate average flood depth relative to the ground floor height of residential buildings. Then the estimated flood depth is used in measuring flood damage procedures.

Before estimating flood damage, it is necessary to have a clear concept of the different aspects of flood damage and flood damage assessment procedures. This study intends to assess economic damage of residential buildings. Therefore, it is necessary to make sure that the study is based on the basic theory and principle of economics. It is also essential to make clear the purpose of the study. Damage assessment procedures with different assessment purposes often lead to different results. For example, insurance companies assess flood damage on the basis of insurance claims. Usually they assess the affected buildings on the basis of the replacement cost of new buildings. On the other hand, mitigation organisations assess affected buildings on the basis of their current market value (EMA 2002).

The following sections of this chapter discuss firstly the concepts of flood damage and then the flood damage assessment procedures used in the study. Key issues covered in the discussion includes types of flood damage, components of flood damage, assessment procedures, economic and financial assessment, insurance assessment, stage-damage curves, and a review of flood damage assessment models.

3.2 TYPES OF FLOOD DAMAGE

The damage resulting from flood can be classified into two main categories; direct damage and indirect damage. In both categories, as shown in Table 3.1, there are also two clear sub-categories including tangible damage and intangible damage (EMA 2002). The definitions of these categories and sub-categories are described as follows.

Flood Damage	Direct	Indirect
Tangible	For example buildings, cars, livestock, crops and infrastructure	For example disruption to transport, business losses elsewhere – not in flood affected areas and legal costs associated with lawsuits
Intangible	For example lives and injuries, damage of memorabilia, damage to cultural and heritage sites	For example stress and anxiety, disruption to living, loss of community and loss of non-use values for cultural and environmental sites and collections

Table 3.1: Types of flood damage

(Source: EMA 2002)

3.2.1 Direct Damage

The damage that occurs immediately after a flood, as a result of the direct physical contact of flood water with people or damageable properties, is called direct damage (National Research Council 1999; Green *et al.* 2000). For example, floodwater damage to the carpets and furniture of a home during flooding.

3.2.2 Indirect damage

The damage which occurs without direct contact with flood water but is the consequence of direct flood damage is called indirect damage (National Research Council 1999; Green *et al.* 2000). Indirect damage often occurs over an extended period of time and is more difficult to estimate (BTE 2001). For example, a business may not be damaged by direct contact with flooding water but its sales could be decreased due to damage to the businesses of upstream suppliers, or the number of customers could be reduced due to transport disruption. In the agricultural sector, a crop may not be damaged during flooding, but the yield of the crop in the following year may be decreased due to a decrease of soil fertility.

The geographical extent of indirect damage is usually broader than the area of direct damage and it is more dependent on social, economical and geographical interactions between flood-affected zones (Rose and Liao 2005).

3.2.3 Tangible damage

Tangible damages are usually taken as that which can be measured in monetary terms such as the damage to the fabric in a factory measured in dollars. This kind of estimation is hardly ever precise and relies heavily upon damage estimation procedures (Green 2000).

Tangible flood damages can be very large. For example, tangible damages caused by the 1988 river flood in Bangladesh is estimated to be as large as $US 1416 million (Islam 1997).

3.2.4 Intangible damage

The damage which can not be assessed in monetary value or typically those for which no market values exist is called intangible damage (BTE 2001). This damage is difficult to estimate as there are no systematic or agreed methods available to measure them. Loss of lives, injuries, stress, loss of heritage items and memorabilia are examples of intangible damage. They can be the most important consequences of flooding because these contain sentimental value (Alee *et al.* 1980; Penning-Rowsell *et al.* 1992) and often can not be replaced or recovered by money or other means.

3.3 COMPONENTS OF FLOOD DAMAGE

The four key components (also known as mechanisms) of flood that commonly cause damage include: depth, velocity, duration, and load (Figure 3.1). The following section describes briefly each of the four main components.

3.3.1 Depth

The depth of floodwater is the greatest contributor to the total damage (Penning-Rowsel and Chatterton 1977). The contribution of the other flood components such as velocity, duration and load might be nominal or absent in flood damage of a particular area, but depth always contributes to the damage and is therefore, a compulsory component to be considered in any flood damage assessment procedure. Flood damage is positively correlated with flood depth. It induces and encourages other components of the flood to contribute to the damage (Smith D.I. 1994).

3.3.2 Velocity

It is evident that the amount of flood damage tends to increase when the velocity of flood water increases (Black and Evans 1999). Sometimes velocity causes substantial damage to properties during floods. Riverine flash floods and dam-break floods can generate high floodwater velocities which are quite capable of sweeping away structures and buildings (New South Wales Government 1986; EMA 1999). Since buildings obstruct flood flows, they can create locally intense flood velocities that can, itself, induce the structural failure of buildings (US Army Corps of Engineers 1998). Buildings close to the watercourse frequently experience undermining as the flood erodes the channel and undercuts the building's foundation.

3.3.3 Duration

Flood duration in a given area can lead to increased flood losses. Industrial flood losses are related to the length of plant outage for both the period whilst it is flooded as well as the recovery period afterwards (Pakers *et al.* 1987). Duration is especially important in agricultural loss assessments. In areas where two or three crops are harvested each year, a flood that extends over the harvesting season for one crop and the planting period for the next can result in both crops being lost (Green, Parker and Emery 1983).

3.3.4 Load

Flash floods often carry large volumes of debris (derived from trees, damaged structures and vehicles) which causes further damage. Oi (1993) provides an example of a 5000 ton boulder that was deposited during the 1993 floods in Monhu Khola, Nepal. Flood water also carries chemicals, salts, and sediments and is contaminated by sewage (Green *et al.* 2000) which contributes to additional damage. For example, if a factory is flooded upstream, poisonous or toxic chemicals that the factory produces or stores can easily contaminate the flood water. This contaminated flood water may cause damage to crops downstream. On the other hand, coastal floods deposit substantial amount of salts onto land which renders them infertile and reduces crop production. Flood water also brings sediments and sands which can, like salt deposits, reduce crop production. However, sediment sometimes makes the land fertile and can increase crop production. On the contrary, flood water in urban areas is frequently contaminated by sewage and spreads disease to communities (Penning-Rowsel and Chatterton 1977).

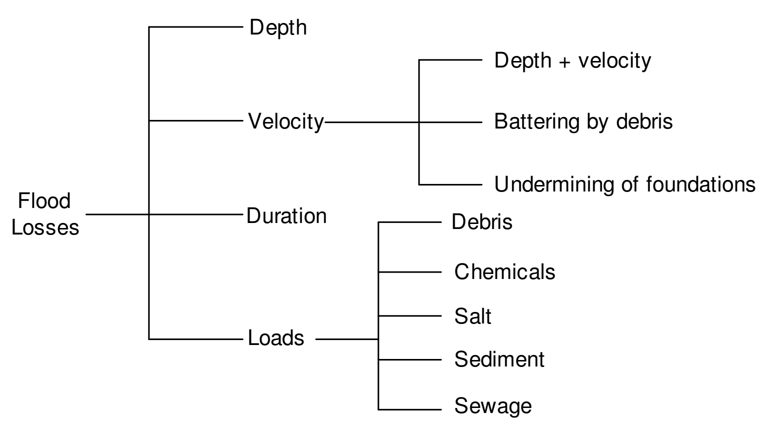

Figure 3-1: Mechanisms of flood damage
Source: Green *et al.* 2000

Some of the flood components are interrelated. For example, velocity and load are positively correlated whilst flood duration is often a function of flood depth (Smith and Tobin 1979). Because of these interrelationships, and the difficulty of making independent measurements, most of the flood estimation methods rely on simpler relationships between flood depth and damage (Smith and Ward 1998). However, in the case of sophisticated assessments, where the appropriate data are available, these depth-damage functions can be modified according to the other components such as flood velocity, flood duration and flood loads.

3.4 TYPES OF ASSESSMENT

3.4.1 Economic assessment

Assessing impacts of a flood or a disaster event on the economy of an area is called economic assessment. An economic analysis usually considers both damage or costs and benefits resulting from the event (EMA 2002). An economic flood damage assessment evaluates the damaged properties as to their economic value in the present market. Organizations and government authorities involved with disaster mitigation, emergency services and flood management are interested in economic assessments. With limited time and the unavailability of suitable data, this study focuses on a GIS-based approach to economic assessment of residential flood damage at property level, and does not cover intangible costs and benefits such as social or environmental items in the economic analysis.

3.4.2 Financial assessment

A financial analysis is concerned with the financial impact on the individual or the entity directly affected by the disaster (BTE 2001). It is usually undertaken to assess the return or loss on an investment from the perspective of a commercial enterprise. Commercial enterprises are interested in the impact of a disaster as it relates to their own profits rather than the impact on the whole economy (EMA 2002). For example, if a business is directly damaged by flood, it is counted as a financial loss for its owner. On the other hand, disruptions in the transportation sector or damage in the government and residential sectors would not be counted as financial losses for that owner but they are considered as economic losses for the community or the government. Similarly, all financial losses are not economic losses. For example, a company may be forced to close in the days following a flood and thereby the company loses its sales market. However, other companies may gain extra profits because of less competition in the market. This situation will result in no net losses to the economy (EMA 2002).

3.4.3 Insurance Assessment

The loss assessment approaches of insurance companies are based on the estimation of the total cost of claims associated with specific flood events. Therefore, insurance data likely excludes both those who are uninsured and costs of damage not covered by insurance (BTE 2001). In Australia, assets like residential properties are generally insured for their replacement values. If a house in the first half of its life expectancy is destroyed by a flood, the insurance policy usually provides the value of a new house, even though its economic value might be worth less. The economic value of a property is determined by its current market value (BTE 2001; EMA 2002). In this study, the current economic value of affected residential buildings is estimated using a depreciation model which will be discussed in Section 6.5.8.

3.5 STAGE-DAMAGE CURVES

Stage-damage curves, as shown in Figure 3.2, are graphical representations of the relationship between potential loss (or damage) of property and depth of over-floor flood water (or stage of flooding) (BTE 2001; EMA 2002). Stage-damage curves are synthetic methods developed for assessing flood damage of buildings and other structures, and have been widely used in Australia, the United Kingdom and USA for estimating flood losses (Thompson and Handmer 1996).

Stage-damage curves were first applied in flood loss assessments in Tennessee, USA in 1964 (Smith 1999). In the 1970's, the stage-damage curves on both the actual and potential datasets were constructed for Britain (Parker and Penning-Rowsell 1972). The approach is now widely accepted and includes five steps (Smith 1999):

- Select the land-use category for analysis.
- Identify the main characteristics of a flood (i.e. variables such as depth, duration, velocity and load)
- Within each land-use category, identify significant sub-groups of building types (such as one or two storey and presence of basement)
- Using the main characteristics (or variables) of the flood, establish a relationship between the variable and damage (such as derive a depth-damage curve) for each land-use sub-group.
- Other flood characteristics, such as velocity, are then used to modify the curve. For example, the stage-damage curve could have low, medium and high velocity variants.

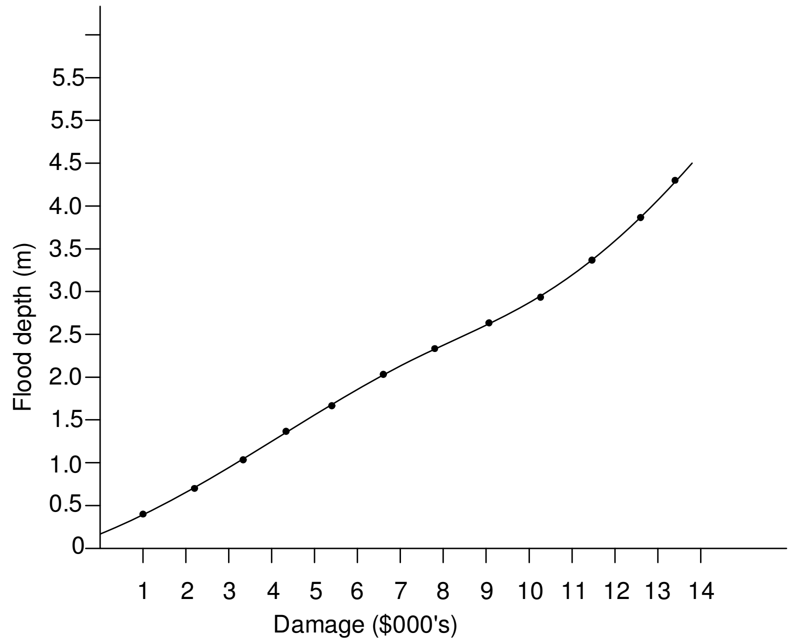

Figure 3-3: Stage-damage curve

(Source: Smith 1999)

Where the appropriate data are available, the stage-damage curves can also be modified according to variables such as flood duration and water quality (Smith 1999).

3.6 AVERAGE ANNUAL DAMAGE

Annual Average Damage (AAD) is calculated, in terms of the damages incurred in an average year, to justify the investment in disaster mitigation. AAD is calculated by plotting the estimated damages for a given flood at a range of magnitudes, against the probability of occurrence of the flood event (EMA 2002).

Floods, like other natural hazards, are infrequent and generally seen as random. When estimating the flood damages of a particular flood event in a given area, the damages resulting from previous floods or future floods in that area is not included. Therefore, the estimated damages can not determine what level of investment in disaster mitigation is appropriate for that area. AAD considers the damages that have resulted from different flood events in different years and represents an average value of the damaged property for an area.

AAD is estimated by aggregating the annual damages from a range of flood events. At least three distinctly different events are required to get some confidence in the estimated results (Smith & Handmer 2002). Damages from different flood events and the probability of their annual occurrence are plotted as shown in table 3.2. Then annual damage is calculated by multiplying yearly probability and damages of an individual flood event. Finally AAD is calculated by aggregating all annual damages.

Flood type	Yearly probability	Damages ($000's)	Annual damage ($000's)
100 year flood	0.01	6	0.06
20 year flood	0.05	3	0.15
10 year flood	0.1	2	0.2
5 year flood	0.2	0.5	0.1
		AAD	**0.51**

Table 3.2: AAD Calculation

(Source: EMA 2002)

If the damages from different floods are plotted against their event occurrence probability as shown in Figure 3.3, the AAD will be equal to the shaded area under the curve.

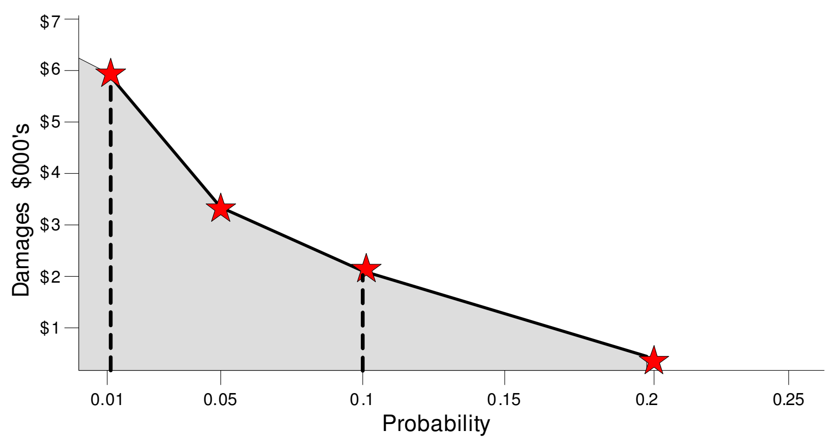

Figure 3-5: AAD Calculation

(Source: EMA 2002)

3.7 TYPES OF APPROACHES TO FLOOD DAMAGE ASSESSMENT

Different approaches to flood damage assessment have been developed for different purposes under different conditions. Some approaches are based on post disaster surveys, attempting to calculate the precise damage; other approaches try to make rapid estimation on the basis of pre-existing datasets and trends (Green, Parker and Emery 1983). The choice of assessment method depends on which type of disaster event the study is focusing on and whether it is an actual or a hypothetical event. The three most common approaches to flood loss assessment are: Averaging Approach, Synthetic Approach and Survey Approach, are described below.

3.7.1 Averaging Approach

Also known as the rapid assessment approach, the averaging approach is conducted largely on pre-existing average data on damages. Read, Sturgess and Associates applied Averaging Approach in their developed model called RAM (EMA 2002), which will be discussed in Section 3.9.2. The averaging approach requires fewer resources and involves simpler and fewer processes compared to other methods. It uses an average loss for each kind of property based on location such as the average loss for impacted dwellings and average value for business premises (EMA 2002).

One of the disadvantages of using this method is that it does not consider the characteristics of the properties; therefore, it places the same value on properties regardless of the quality of the building.

Figure 3.3 shows the steps in the averaging approach, and the shaded area highlights information required to be collected from the study area.

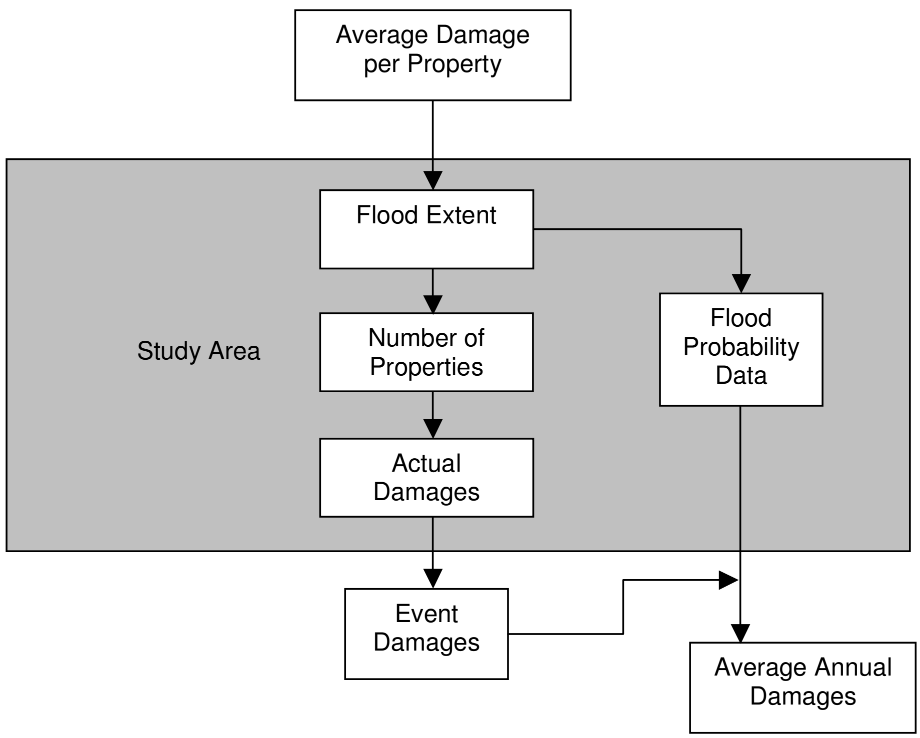

Figure 3-7: Schematic diagram of Averaging Approach

Source: EMA 2002

3.7.2 Synthetic Approach

The Synthetic Approach is the most flexible and in recent times the most widely used approach for flood loss assessment in the world (EMA 2002). It produces synthetic or predicted values, rather than actual and direct values and the values are modified with existing sampled data. The results derived from the synthetic method can be easily transferred to areas where flood experience is either non-existent or outdated (Smith and Ward 1998).

The Synthetic Approach is based on generalised relationships between certain flood characteristics and physical damage. These relationships can then be transferred into a table or displayed as curves. From this table or curves the severity of the flood can be measured (EMA 2002). Section 3.5 has already discussed stage-damage curves.

The Synthetic Approach involves compiling detailed average inventories of property contents for different structure types such as, the height of the ground floor and the cost of repairing the damage. It is important to compare known actual damage (surveyed damage data) with synthetic damage (predicted data) to refine the methodology. It is important to realise that unmodified synthetic damage can be higher than actual recorded damage because they ignore the damage reduction actions that emergency managers and the flood victims take in a flood event (EMA 2002).

Figure 3.4 shows the steps in the Systematic Approach, and the shaded area highlights information required to be collected from the study area.

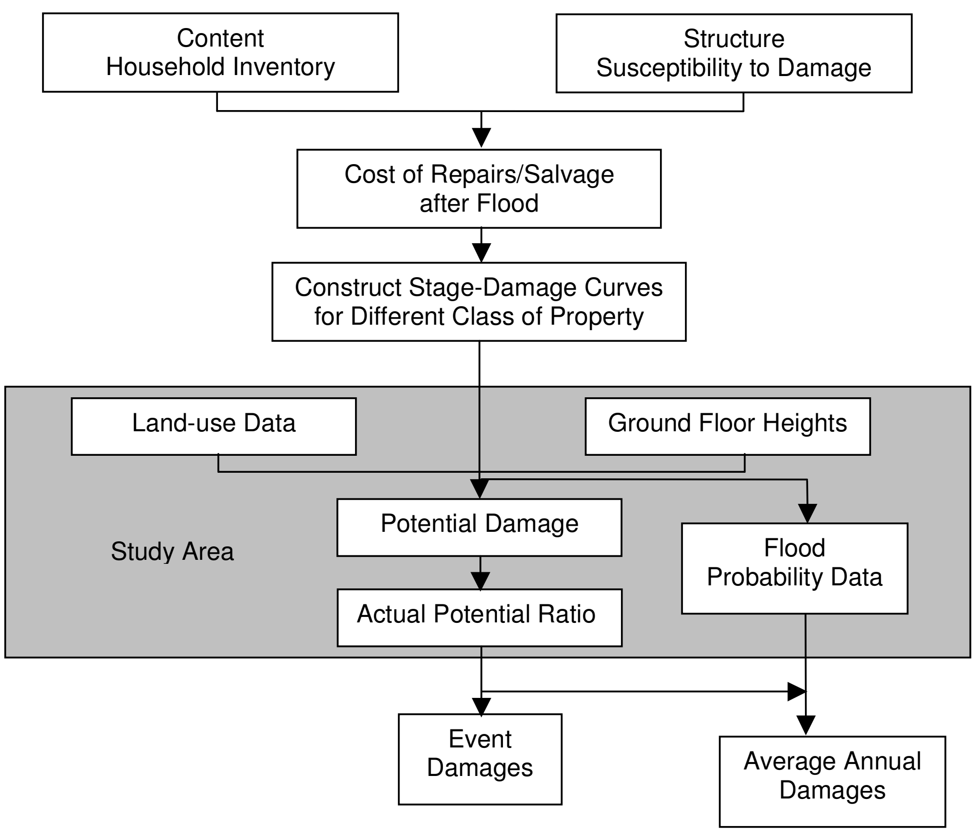

Figure 3-9: Schematic diagram of Synthetic Approach (Source: EMA 2002)

The Synthetic Approach can be applicable to all levels of flood damage assessment – individual properties to larger area assessments. At all levels of assessment, appropriate stage-damage curves, flood data and building inventories are required as an input data. The Synthetic Approach predicts the damage to the buildings or assets which may be different to the survey data for an individual property. Policy makers at all levels such as catchment authorities, emergency management authorities, mitigation authorities and insurance companies need the accumulative damage data induced from a whole community rather than an individual property damage. Therefore, they prefer the Synthetic Approach over all other approaches (Islam 1997).

3.7.3 Survey Approach

The Survey or historical approach is based on field interviews and questionnaires on damage from a recent flood. Basically it involves two steps. The first step involves taking a sample of the households or enterprises. The second step involves generalising the result to all of the affected population. In this approach, a more sophisticated analysis is sometimes needed where a substantial number of properties are involved. It is also essential to develop different stage-damage curves for different events and structure types using regression techniques (EMA 2002).

As this approach is based on survey data, it requires a flood to happen first. Therefore, an area having more frequent flood experiences contains better data compared to other areas having less frequent experiences (Smith and Ward 1998).

Though it is based on actual flooding, sometimes this may not provide information on actual damage. For example, if the survey is conducted immediately after a flood, the people tend to over-estimate direct damage because they have not received the repair bills. On the other hand, some types of long term structural damage such as undermining of the foundations or wet rot to floor-boards may not be detected until much later. However, if the survey is made months later, flood victims may be unable to recall the important things (Smith and Ward 1998).

Figure 3.5 shows the basic steps of the survey approach, and the shaded area highlights information required to be collected from the study area.

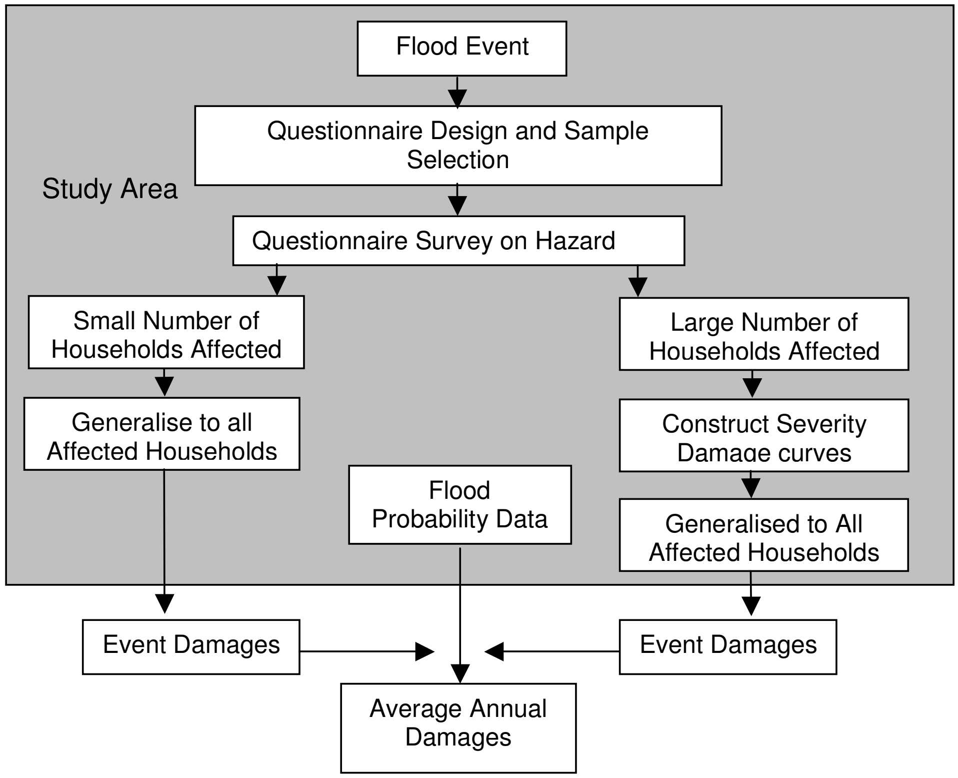

Figure 3-11: Schematic diagram of Survey Approach

Source: EMA 2002

3.7.4 Flood damage assessment approaches for the study

The aim of this study is to develop an economic assessment procedure for residential flood damage at property level in fine resolution using readily available data. Among the three approaches discussed, the Averaging Approach can not produce a satisfactory level of accuracy for the study; the Survey Approach can produce satisfactory levels of accuracy but it requires extensive survey and resources. Only the Synthetic Approach can produce reasonable accuracy of damage estimation using readily available data. Moreover, in the Survey Approach sampled data for an area may not be applicable to other areas or even other years. Moreover, damage estimates in a place resulted from Survey Approach may be inconsistent with the estimates in other place and it does not applicable for a hypothetical flood event. However, Synthetic Approach provides consistent estimation which can be applicable on a hypothetical flood event. Therefore, the study adopts the Synthetic Approach in developing the damage estimation procedures.

3.8 REVIEW OF FLOOD DAMAGE ASSESSMENT MODELS

Many flood damage assessment models are used in different organisations in different countries. This section discusses three renowned models for flood damage assessment which includes:

- HAZUS model,
- RAM model, and
- NHRC curves
- BTE report

3.8.1 HAZUS model

HAZUS model (formally named as HAZUS MR1) was developed by the Federal Emergency Management Agency (FEMA) under a cooperative agreement with the National Institute of Building Sciences (NIBS) in the USA. The final version of the model was published in 2003 (FEMA 2003b). The model has been developed based on ESRI's GIS software called ArcGIS, and requires ArcGIS version 8.3 or better and the associated extension (Spatial Analyst) to perform flood loss estimation. The model can be used to estimate the direct physical damage resulting from wind, flood and earthquake. In the HAZUS model, the finest resolution of the study area is set at the Census Block level, on which all data are collected and organised, analyses are performed and results are derived (FEMA 2003a). A Census Block is the smallest geographic unit used by the United States Census Bureau for presenting their census data. There are about 8.5 million blocks nationwide in the USA (US Census Bureau 2007).

The overall objective of the HAZUS MR1 project was to develop nationally applicable standardised multi-hazard methodologies for estimating potential damages that may result from wind, flood, and earthquake in the USA. The model was intended to be used by local, state, and regional officials for planning and stimulating mitigation efforts to reduce damages from hurricanes, severe floods and earthquakes and preparing for emergency response and recovery following these events.

The model places more emphasis on flood hazard than on wind and earthquake. The flood methodology of the HAZUS consists of two basic analytical processes:

- flood hazard analysis and
- flood loss estimation analysis.

In flood hazard analysis, flood characteristics such as frequency, discharge, and ground elevation are used to model the spatial variation in flood depth and velocity. The flood model is inherently dependant on the Digital Elevation Model (DEM) of the ground surface elevation which can be downloaded from USGS website or supplied by users who run the software. The model uses DEM and default flood data incorporated in the software to produce basic flood model. The output accuracy is more reasonable at coarse resolution. To achieve accurate output at fine resolution, the Flood Information Tool (FIT) provided by the HAZUS model, is required. FIT enables users to incorporate the analysis of fine resolution input data such as precise DEM for ground surface elevation, stream cross section attributed with flood elevation, flood plain boundary and stream network.

In the flood loss estimation analysis, structural and economic damage is calculated on the results of the hazard analysis through the use of vulnerability curves (stage-damage curves). The model can be used to assess: (1) the structure and contents damage of different kinds of buildings such as residential, commercial, industrial, agricultural, religious/non-profit, governmental and educational; (2) the damage to essential facilities, transportation systems, lifeline utility systems, agricultural product and vehicles; as well as (3) the direct economic and social losses resulting from a flood.

The model comes with a suite of stage-damage curves including most of the available curves from the Federal Insurance Administration which are developed on the basis of extensive field survey and the most reliable curves in the USA.

The HAZUS model consists of three levels of analyses on the basis of data accuracy, volume of effort needed, and level of technical knowledge required. Level-1 is the simplest type of analysis requiring minimum effort by the user as it is based mostly on input provided by the software itself. This analysis may produce a crude estimation for a specific area. The Level-2 analysis intends to improve the result from Level-1 by considering additional data that is readily available or can easily be converted or computed to meet the methodological requirements. The Level-3 analysis requires extensive efforts by the user in developing information on flood hazard and measure of exposure. At this level, one or more technical experts would be needed to acquire data, perform detailed analysis, assess damage/loss, and assist the user in gathering more extensive inventory. This level obviously produces most accurate damage assessment between all three levels of analysis.

The HAZUS model has been carefully studied when developing an economic damage assessment method for the study. In fact, this study has adopted in its assessment procedures building occupancy classes, building depreciation model and a few stage-damage curves from the damage assessment procedures of the HAZUS model.

3.8.2 RAM model

RAM is the shorthand for Rapid Appraisal Method for Floodplain Management. RAM was developed by the Victorian Department of Natural Resources and Environment under a cooperative agreement with Read Sturgess and Associates, and the model was published in 2000 (Reed Sturgess and Associates 2000). The model evaluates floodplain management measures in a cost benefit analysis framework and includes a rapid method for assessing flood damages. There is no indication of either a minimum spatial resolution to be used or the most reasonable area size (for example Census District, suburb or city council) for representing the estimated result. It is reasonable to assume that a coarse spatial resolution and a bigger study area is more appropriate for RAM as the analysis is based on mean unit cost of the damaged assets.

The objective of RAM was to make a rapid and consistent approach for assessing benefits and costs of floodplain management measures. The consistency is required in order to ensure comparability between evaluations. Rapidity is required primarily because of the number of floodplain management programs requiring evaluation and because of limited funds available for the evaluation of those programmes.

RAM assesses all types of flood damage including direct (tangible), indirect (tangible) and intangible damage. The direct damage assessment includes all types of buildings, infrastructure and agricultural enterprises.

RAM assesses building damage with a map showing the flood extent, a rapid survey of large non-residential buildings within the flood extent and a simple count of the total number of residential and small-medium size non-residential buildings. The damages estimation is based on a mean cost of $20,500 per building for all except large non-residential buildings. The damages estimation for large non-residential buildings is based on the values shown in Table 3.3.

Value of contents	Mean potential damages per square metre (includes external, internal contents and structural damage)
Low (that is offices, sporting pavilions and churches)	$45
Medium (that is libraries, clothing businesses, caravan parks)	$80
High (that is electronic, printing)	$200

Table 3.3: Per square metre damages for large non-residential buildings (>1000 square metre)

Source: Reed Sturgess and Associates (2000)

The magnitude of damage can be influenced by the length of early warning times and the flood experiences of the community involved. These aspects can be included in the assessment procedure by multiplying damage with a ratio of actual and potential damage. Here potential damage refers to the likely damage if no remedial action of any kind is undertaken before and during a flood event. On the other hand, actual damage refers to the resultant damage with a remedial action undertaken for the reduction of damage (Reed Sturgess and Associates (2000). For example, if property owners have time they take valuable items or cars away from the property, or raise valuables to a height above the likely level of inundation. The ratios of actual and potential damage are shown in Table 3.4.

Warning time	Experienced community	Inexperienced community
Less than 2 hours	0.8	0.9
2 to 12 hours	Linear reduction from 0.8 at 2 hours to 0.4 at 12 hours	0.8
Greater than 12 hours	0.4	0.7

Table 3.4: Ratios of actual: potential damage;

Source: Reed Sturgess and Associates (2000)

RAM is now widely used in different organisations in Australia. It provides useful conceptual and theoretical ideas of flood damage assessment to this study in addition to some case studies on Australian flood and flood damage assessment.

3.8.3 NHRC Curves

In 2001, Natural Hazards Research Centre at Macquarie University conducted a study to developing a set of curves for assessing the contents and structural damage of buildings as a result of floods. The curves were based on FLAIR data which were produced by the Flood Hazard Research Centre at Middlesex University and have been modified for Australian conditions (Leigh *et al.* 2001).

The objective of the NHRC curves was to provide a set of suitable stage-damage curves of residential property damage for insurance purposes, including:

- stage-damage curves for contents,
- stage-damage curves for buildings, and
- combined stage-damage curves for buildings and contents.

The NHRC curves were developed because it was considered that mainstream flood damage estimation curves for residential properties (such as ANUFLOOD, which will be discussed in Section 6.5.1) were not suitable for modern insurance purposes. Most of the damage curves used in Australia rely on Average Remaining Value (usually 50%) whereas most household insurance policies offer ‘new for old’ replacement.

In developing stage-damage curves for contents, the model adopted FLAIR room by room damage data. Then the damage data for individual rooms were integrated and compared with the surveyed damage data of the Georges River flood which occurred in 1986. The comparison suggested that there was a good agreement between the adopted integrated curves and the contents damage pattern of the Georges River flood.

In developing stage-damage curves for buildings, NHRC also adopted FLAIR data which was compared with US damage data developed by the Federal Emergency Management Authority (FEMA) for single-storey residential buildings. However, the NHRC curve was based on potential damage whereas US curves were based on actual damage.

In developing combined stage-damage curves for buildings and contents, NHRC did not simply sum up the contents and structural damage, but also combined them using a set of ratios of contents and structural damage. NHRC suggested that the set of ratios range from 0.2 to 0.5 according to available Australian flood damage data. NHRC also compared the combined curves with a few other curves developed in different periods and suggested that NHRC curves were more similar to recent curves than the old ones.

NHRC curves were based on UK curves and were tested with Australian floods. These curves are the most current ones which are widely used in Australia (Leigh 2006). Therefore, this study intends to evaluate the NHRC curves and use them in flood damage estimation procedures. Section 6.6 discusses more on adopting NHRC curves.

3.8.4 BTE Report

The economic costs of natural disasters in Australia for the period of 1967 to 1999 are assessed in the report ”Economic costs of natural disasters in Australia” published by Bureau of Transport Economics (BTE, 2001). The report aims at:

- establishing the costs of natural disasters in Australia over time,

- analysing the trends in these costs and
- developing a model for estimating the costs of future disasters.

The report focuses on national economic costs, categorises the costs into three such as tangible direct, tangible indirect and intangible, and chose an economic rather than financial approach. (see Section 3.4 for the clarification on economic and financial assessment).

Reviewing of the BTE report helps understanding various conceptual aspects of flood damage assessment procedure and accomplishing the study aims specially in the calculation of depreciating building replacement value (see Section 6.4.8 and Appendix B). Given the scope of this study, however, a local and spatially distributed approach is more appropriate..

3.9 CONCLUSION

The aim of this study is to develop an economic assessment procedure for residential flood damage at property level. It only considers the direct tangible damage. However, the study provides the basis for further study to incorporate indirect and intangible damage.

To achieve the aim of the study, previous sections of this chapter have discussed the theoretical concepts of flood and flood damage. This chapter has also discussed the basic approaches to flood damage assessment. Among the approaches, The Synthetic Approach is widely used around the world and well accepted, therefore, the study intends to follow the Synthetic Approach.

This chapter has also reviewed three renowned flood damage estimation models. None of them estimate the damage at property level or provide reasonable accuracy at fine resolution which the study intends to achieve. The review points towards a successful result for this study.

The next chapter discusses the framework of economic damage assessment for the study. The discussion consists of five sections: flood mapping, building inventory, adopting stage-damage curves, measuring damage and results validation.

CHAPTER 4:

A FRAMEWORK FOR ECONOMIC ASSESSMENT OF RESIDENTIAL FLOOD DAMAGE

4.1 INTRODUCTION

Chapter 3 reviewed the conceptual aspects of flood damage and their assessment procedures, including different types of flood damage, methods of flood damage assessment, stage-damage curves and models of flood damage assessment. This chapter presents a framework of economic assessment of residential flood damage which this study intends to deploy.

Between the three flood damage assessment methods reviewed, this study favours the conceptual framework of the Synthetic Approach which consists of three major processes: (1) developing a detailed building inventory dataset to classify the characteristics of buildings; (2) developing a set of stage-damage curves and tables on the basis of known data; and (3) applying stage-damage curves to the building inventory dataset according to building characteristics and synthesising the damages of the buildings. In addition, this study also uses a set of models in different stages of its analytical processes. The following sections of this chapter discusses: (1) the analytical procedure for economic assessment of residential flood damage, and (2) the validation of the results derived from the procedure by comparison with other models and data.

The overall methodology developed in this study for assessing economic damages due to floods consists of four key analytical processes (Figure 4.1):

1. Flood modelling
2. Building inventory
3. Adopting stage-damage curves
4. Measuring damage

Flood modelling uses flood extent and flood level cut line data to produce a flood level surface map. The Digital Elevation Model (DEM) of ground elevation is used to generate a flood depth surface map. Building inventory collects and organises data on building characteristics from the affected properties. In most cases, there is a one-to-one relationship between property and building in the study area. When more than one building are found within the boundary of a property, building level figures can be aggregated to the property level. Adopting stage-damage curves involves converting the curves into a damage table which are used for measuring damage. Measuring damage needs both the depth of flood water relative to ground floor height at each property and the damage table adopted from stage-damage curves.

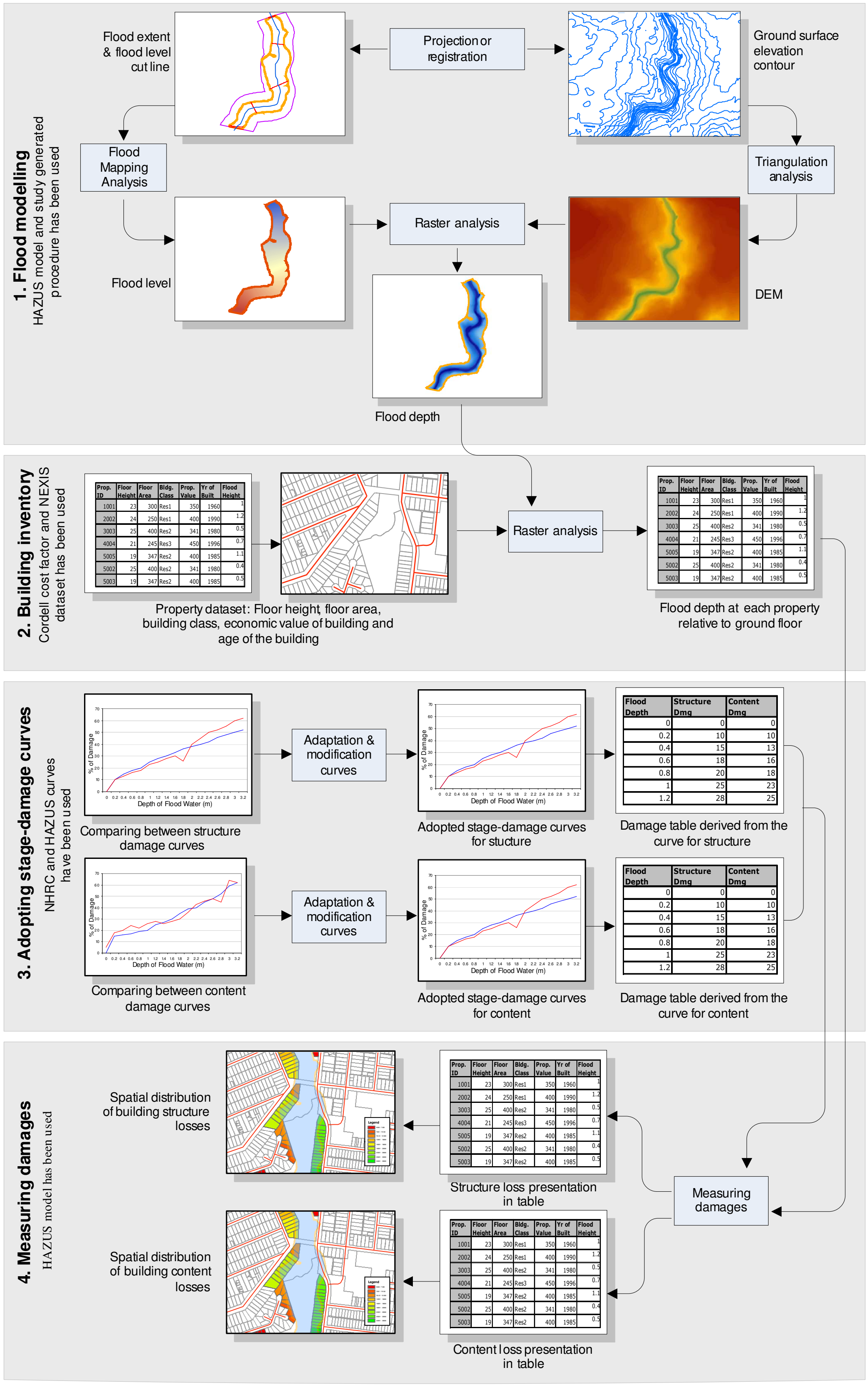

Figure 4-1: Overall methodology for assessing economic damages due to flood

4.2 FLOOD MODELLING

Flood modelling conducted in this study aims to determine the average flood water depth in buildings relative to their ground floor height. Flood as a hazard usually exhibits a certain chance for a specific magnitude of flooding (flood depth). Therefore, flood can be expressed either in time periods or in flood depth. The study considers a 100 year flood, a rare and usually devastating event that has an occurrence chance of 1% in a year. .

The flood modelling involves three key aspects: (1) identifying the stream network, (2) conducting a hydrological analysis, and (3) mapping the flood surface (FEMA 2002a). The stream network is identified with a digital elevation model of ground surface using the Spatial Analysis toolbox in ArcGIS. A more accurate DEM yields a more accurate stream network. Delineation of stream network is performed where there is no suitable stream network data available. This study uses stream network data obtained from the Victorian Department of Natural Resource and Environment (NRE).

The hydrological analysis involves the analysis of river gauge data, flood hydrograph, DEM, stream network and historic flood data, and aims to determine flood extent and flood level cut lines at different river cross sections. Flood level is assumed to be the same along a cut line of the river. Extensive field work, data processing and data analysing processes are needed to model an accurate flood extent and flood depth. This study uses a dataset of a predefined extent of 100 year flood and flood level cut lines obtained from Melbourne Water. Section 6.2.1 provides more discussion on the dataset of the flood extent boundaries and flood level cut lines.

Mapping flood surface requires datasets such as stream network, flood level cut line, and flood extent derived from flood modelling and hydrological analysis. A DEM of ground surface elevation is also required to obtain flood depth surface maps. Figure 4.2 shows the procedure for mapping the surface of flood depth, which involves the following steps: (1) split up the whole stream into some manageable sections called reaches on which flood mapping is performed individually; (2) define flood extents for each reach on the basis of up- and down-stream cut lines as well as left and right side flood plain boundaries; (3) delineate the centreline of the flood extent boundary; (4) create flow corridors parallel to the centreline; (5) create flood level arcs and points and interpolate their value from up- and down-stream flood level cut lines (a position closer to a cut line will have more influence to determine its flood level than if it is further away from the cut line; this process generates several points at one meter interval which contain flood level information); (6) generate flood level surface by converting flood level points into a raster surface; (7) generate flood depth surface by conducting a raster analysis which deducts the DEM of ground surface elevation from the generated flood level raster surface.

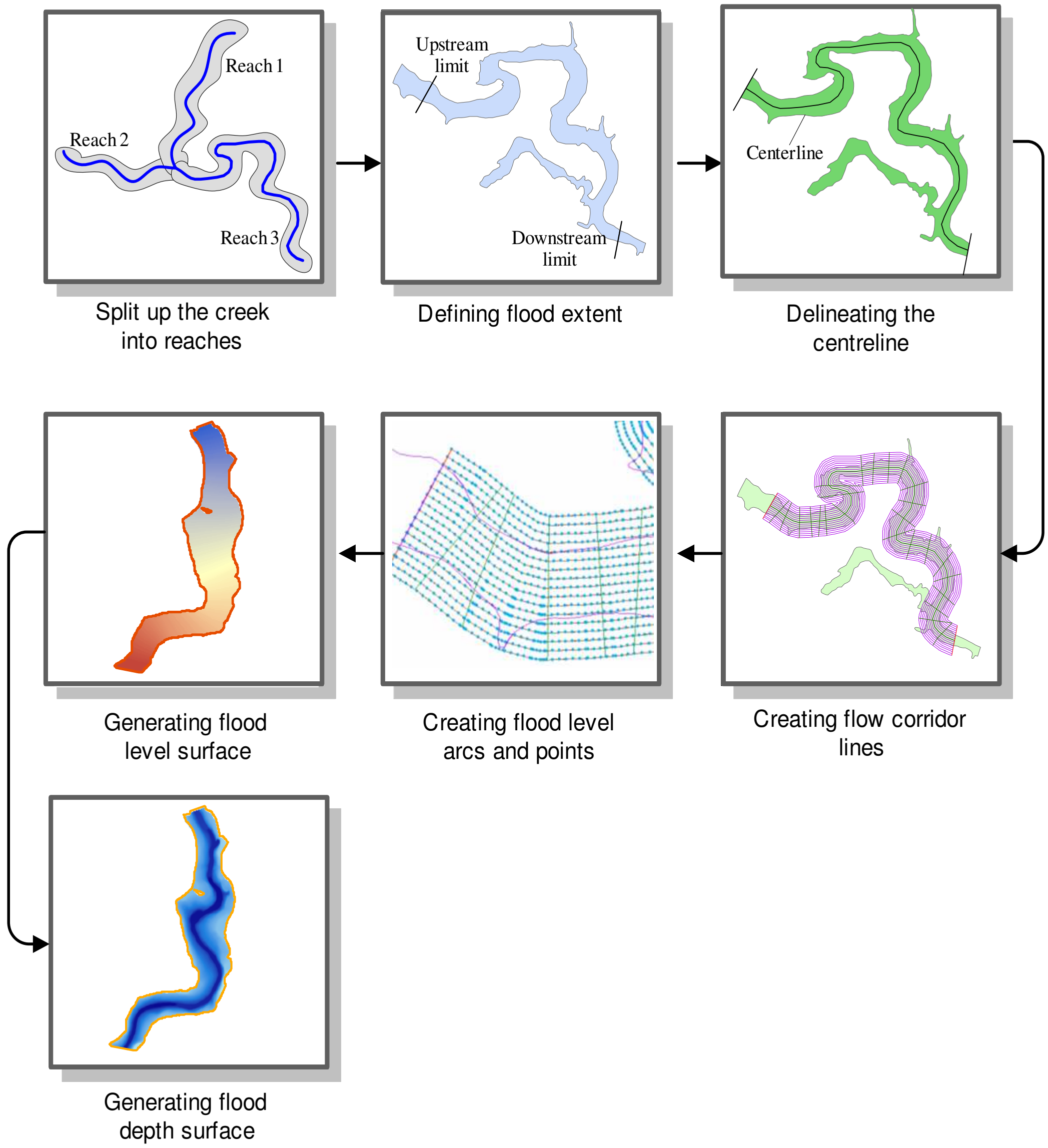

Figure 4-3: Flowchart for mapping surface of flood depth.

4.3 BUILDING INVENTORY

Building inventory collects and organises data of buildings that are potentially vulnerable to a 100 year flood event. The data includes building characteristics that are sensitive to flood depth. For example, damage to a one-storey single family building is different from damage to a two-storey multi family building. In addition, two buildings that have the same type of occupancy (such as single residential building) may vary in the amount of damage due to the variation of ground floor height as lower ground floor height allows in more flood water and may cause more substantial damage. Therefore, building inventory is an important component in flood damage estimation. A wide-ranging and quality building inventory leads to precise damage estimation.

The building inventory process in this study involves identifying relevant building characteristics such as occupancy classes, number of storeys, floor space, materials used for constructing buildings, household income, building replacement value, building age, depreciation of building replacement value, ground floor height and contents value. Figure 4.3 shows the process of the building inventory and Section 6.4 discusses more about the building inventory carried out in this study.

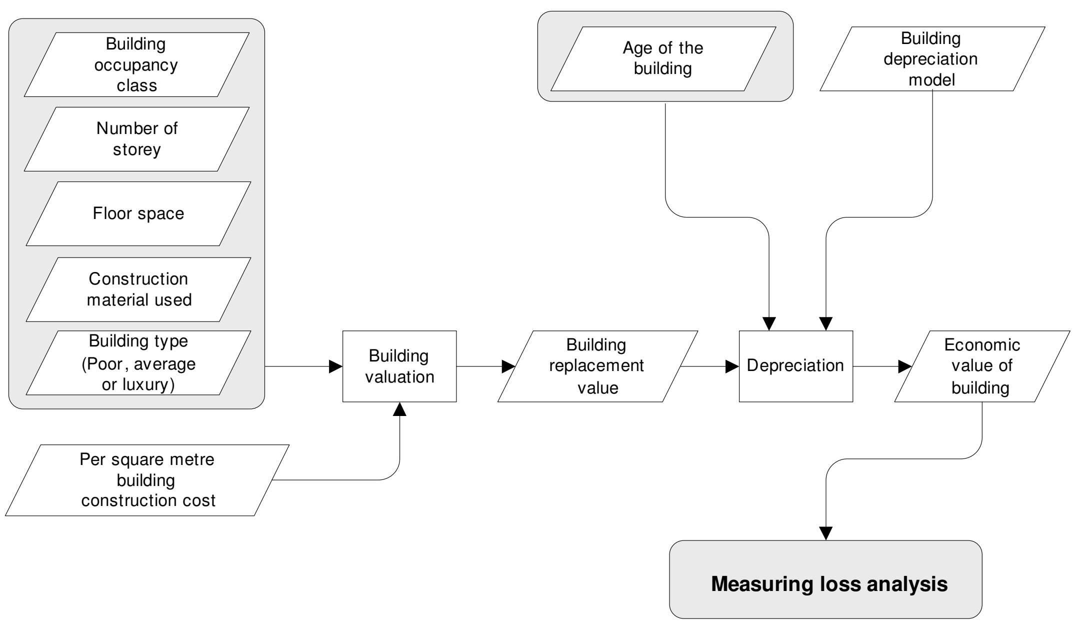

Figure 4-5: Schematic diagram for the estimating building replacement value

4.3.1 Classification of building occupancy

Organising buildings according to the occupancy class is one of the most important processes of building inventory. Damage to a building varies considerably with different building occupancy. A range of stage-damage curves for different occupancy classes are adopted in this study (Section 6.6 provides more discussion on adopting stage-damage curves). The curves are applied to buildings on the basis of their occupancy classes such as RES1, RES2, RES3, RES4, RES5 and RES6. More specific stage-damage curves and refined building occupancy classification can improve the quality of damage estimation.

4.3.2 Number of storeys and floor space of the building

Floor space is needed for building valuation (as shown in Figure 4.3). In this study, floor space for a single storey building is calculated from the building's footprint delineated from an aerial photograph. To obtain the total floor space for a multi-storey building, the area of its footprint is multiplied by the number of storeys. The number of storeys is important for choosing appropriate stage-damage curves for the building. Sections 6.5.2 and 6.5.3 will discuss more regarding building storeys and floor space using a case study approach.

4.3.3 Materials used for constructing buildings and household income

The Cordell dataset includes per-square metre building replacement costs for a range of building categories which are basically based on the building material used for construction (Section 6.2.2.2 discusses in detail the Cordell dataset). This study intends to use the Cordell dataset. Therefore information on building construction material is required in the building valuation process to choose an appropriate per-square metre construction cost from this dataset. Cordell further classifies building replacement value on the basis of building economic condition; therefore mean household income is another set of information needed in the building valuation process.

4.3.4 Building replacement value

Building replacement value means how much money is required to reconstruct a building or a portion of a building. The process of determining the building replacement value needs a per-square metre replacement cost which is available from the Cordell dataset. The information on occupancy classes, building construction materials, and mean household income helps to determine the appropriate per-square metre replacement cost from the Cordell dataset for each individual building. The determined per-square metre data is then multiplied by the floor space of the building to calculate the building replacement value. Section 6.5.6 discusses further the building replacement value using a case study approach.

4.3.5 Age and depreciation of building replacement cost

Information on building age is used to obtain economic value of a building by applying a depreciation model.

According to economic principles, depreciation means the decline in dollar value of an asset over time due to use, obsolescence (becoming useless) or destruction (as by fire or flood) (Saliers 1980). When an asset or a building is damaged by floods, it is the depreciated value rather than replacement value of a new building that needs to be calculated. Howe and others (1991) suggest that if an asset or building needs replacement, the theoretically correct approach is to measure the changes of anticipated returns (goods and services that the assets or buildings could produce) in present value with and without the flood (Howe *et al.* 1991).

There is a significant difference between insurance damage assessment and economic damage assessment (BTE 2001). Typically, insurance assessment considers full replacement cost of buildings or assets if it is damaged by floods as their policy commits to provide new in replacement of old. These estimated damages may considerably overstate the economic value of the damaged buildings or assets. If a building or an asset is damaged by floods while halfway through its life, the economic damage will be only half of its replacement value, while the insurance assessment may provide full replacement value. This study intends to find a method to estimate direct economic damage of residential properties.

Previous sections have discussed the building replacement value which is actually the cost of constructing new buildings and does not reflect their present economic value. Therefore, the estimated value of buildings is depreciated on the basis of age to determine their present economic value. This study adopts the depreciation model from HAZUS to estimate the economic value of buildings, Sections 6.5.7 and 6.5.8 discuss more on building age and the depreciation of building replacement cost using a case study approach.

4.3.6 Ground floor height

Information on ground floor height measured in metres above AHD (Australian Height Datum) is required to estimate flood depth in buildings. This study only uses ground floor height of the main building for its analysis.

4.3.7 Contents value

Contents value of a building means the total value of all items in that building, including carpets, furniture, appliances etcetra. Information on the contents value of buildings is needed in contents damage analysis, and can be derived from factors such as total floor space of buildings and household income.

4.4 ADOPTING STAGE-DAMAGE CURVES

Stage-damage curves are graphical representations of the relationship between flood depth and building damage. If the depth of flood in a building is known, the structure and contents damage to the building can be measured using the curves. This study evaluates two sets of stage-damage curves including that of HAZUS and NHRC. Section 6.6 discusses more on adopting stage-damage curves using a case study approach.

4.5 MEASURING DAMAGE

This study measures both structural and contents damage to residential buildings. In the process, depth of flood is calculated at each building relative to its ground floor height. The adopted stage-damage curves are applied to the building to obtain the damage in percent for the flood depth at the building. The damage to the buildings in percent is multiplied by building economic value and contents value to obtain structural damages and contents damages in dollars, respectively. Section 6.7 discusses more on measuring damage using a case study approach.

4.6 VALIDATION

The validation process is an important part of any research study. It verifies the method the study implies and the result derived from the implied method. This process is usually conducted by comparison with similar types of methods or with results derived from other methods.

The method of the study is based on concepts and theories derived from careful reviews of credible literature. The study adopts and uses several renowned and widely used disaster damage assessment models such as HAZUS, NHRC and RAM. The study method is validated in terms of flood level, floor space and stage-damage curves, as detailed in Section 6.8.

4.7 CONCLUSION

For carrying out economic assessment of residential building damage caused by floods, the study has developed a framework involving flood modelling, building inventory, adopting stage-damage curves and measuring damage.

The flood modelling process maps a flood depth surface layer. The building inventory process estimates value of assets exposed to floods. The adopting stage-damage curves process chooses appropriate curves for each individual building and finally the measuring damage process estimates flood depth in buildings and calculates the potential damage to them in dollar value.

To apply the developed procedures of economic assessment of residential flood damage in a flood affected area, a segment of Kororoit Creek and its adjacent area has been chosen as the case study area. Chapter 5 discusses various aspects of the study area relevant to the application of the procedures. Detailed discussion on how the framework could be applied in the study area is given in chapter 6, where detailed procedures of the framework presented in this chapter are also given.

CHAPTER 5:

THE STUDY AREA: A SEGMENT OF KOROROIT CREEK AND ITS ADJACENT AREA

5.1 INTRODUCTION

This study intends to develop and demonstrate a GIS based approach to economic assessment of residential flood damage at property level. Chapter 4 outlined the developed method. In this chapter, a selected study area is presented to set up a real world test for implementing and demonstrating the developed method. The study area is presented in terms of its location, geomorphology, flood-prone land use, settlement history and building pattern, and flood history.

5.2 LOCATION

The study area is of a segment of the Kororoit Creek catchment and the adjacent flood-prone areas located in the western suburb of Melbourne, Australia. The Kororoit Creek starts from Toolern Vale and Diggers Rest northeast of Melton, passes through Rockbank, Caroline Spring, Deer Park, Cairn Lea, Sunshine, Brookline, and Altona where it enters Port Phillip Bay, with a total length of about 45 kilometres (DPCD 2006). The segment of Kororoit Creek taken in the study passes though four suburbs: Albion, Sunshine, Sunshine West and Brooklyn (Figure 5.1). The length of the segment is about 11 kilometres. The decision to take this segment of Kororoit Creek for flood modelling is influenced by its easy accessibility for field work and the availability of relevant digital datasets (e.g. flood extent, flood level cut lines, ground level floor height, flood depth) for implementing the developed methodology. This methodology should be applicable to the whole creek or even other river segments in Australia for assessing the economic damages of residential buildings affected by flood if required datasets are available. Figure 6.14 shows the location of the properties prone to a 100 year flood event in the study area.

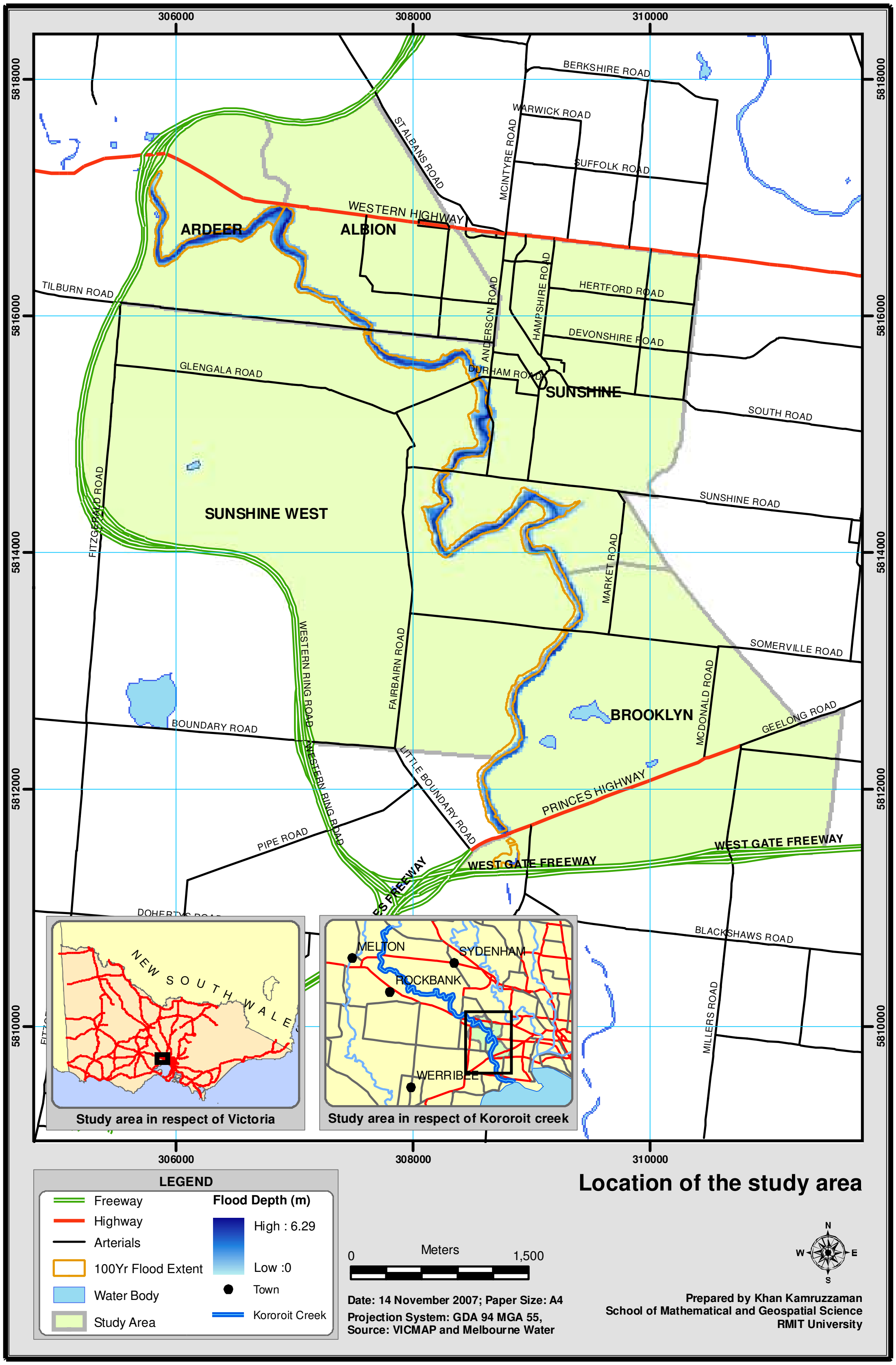

Figure 5-1: Location of the study area

5.3 GEOMORPHOLOGY

Kororoit Creek flows over a basalt plain created by volcanic activities about one to five million years ago. This characteristic of the subsurface makes the creek unique (MWRC 1984). Surface rocks and basalt outcrops throughout the creek encourage flooding on adjacent areas of the creek by influencing the flood intensity factors such as water storage, infiltration and transmissibility processes.

The steepness of the embankments of the Kororoit Creek varies in its different sections. The embankment of the creek is steep along the upper section, becomes gentle in the middle section, and remains steep in the lower section. The study area is situated on the lower part of the Kororoit Creek which is more vulnerable to flooding.

Apart from the embankment steepness of Kororoit Creek, the study area is characterised by a wide range of ground elevations which extend from 15 to 60 metres above mean sea level. This variation of the surface elevation theoretically enhances flooding in lower parts of the study area (MLMW 1986). Figure 5.2 shows the elevation of the ground surface in the study area.

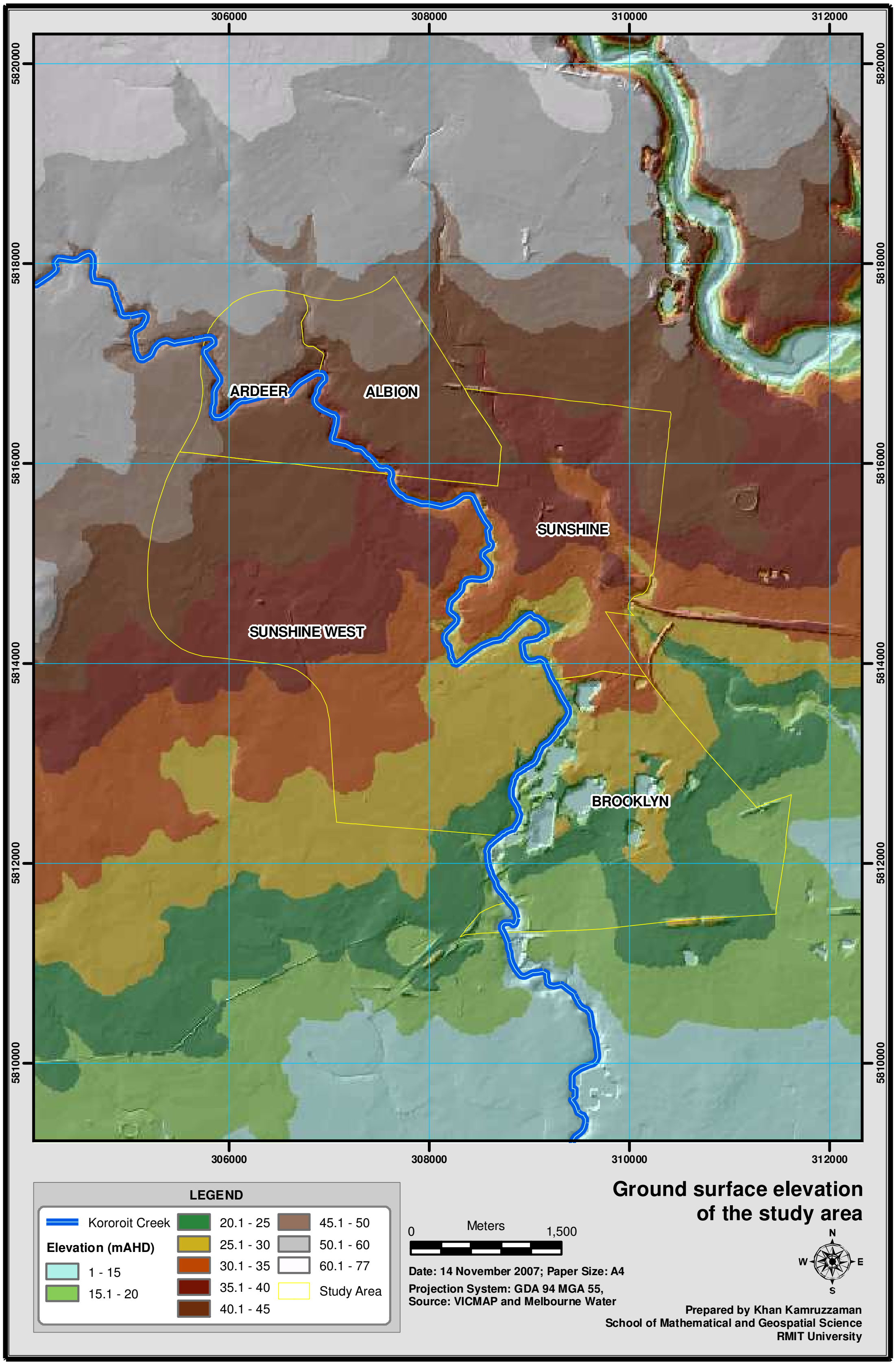

Figure 5-3: Ground surface elevation of the study area

5.4 FLOOD-PRONE LAND USE IN THE STUDY AREA

In this study, the 100 year flood is regarded as the probable maximum flood event. As shown in Table 5.1 and Figure 5.3, land uses of the study area that are prone to the 100 year flood include: residential, commercial, industrial, park and recreation zones.

According to Table 5.1 and Figure 5.3, more than 40% of the flood-prone area is in the Industrial Zones, almost one-third of the flood-prone area is occupied by more than 200 residential properties, and about one-fifth of the flood-prone area is covered by parks and showgrounds.

Although the area is suitable for using as a case study for economic assessment of industrial properties, residential properties and park land damage caused by a flood, only residential properties that are prone to the 100 year flood events are considered in this study.

Land use code	Description	Number of properties	Total area HA	Area in percent
IN1Z (Industrial Zone 1)	Manufacturing industry, the storage and distribution of goods and associated uses in a manner which does not affect the safety and amenity of local communities	27	71.92	36.25
IN2Z (Industrial Zone 2)	same as IN1Z but it supports other manufacturing industry	4	8.47	4.27
IN3Z (Industrial Zone 3)	Industries and associated uses in specific areas where special consideration is required	1	4.93	2.49
PPRZ (Public Parks and Recreation Zone)	Public recreation and open space.	27	31.85	16.06
PUZ1 (Public Use Zone 1)	Public land use for service and utility	9	11.71	5.90
PUZ6 (Public Use Zone 6)	Public land use for local government	1	0.08	0.04
R1Z (Residential Zone 1)	Residential development at a range of densities with a variety of dwellings	204	58.54	29.51
RDZ1 (Road Zone - Category 1)	Significant existing roads	1	0.05	0.03
SUZ2 (Special Use Zone)	Land use for specific purposes such as showground	1	9.48	4.78
UFZ (Urban Flood Zone)	Waterways, major footpaths, drainage depressions and high hazard areas within urban areas	1	1.34	0.68
	Summary	**276**	198.38	100.00

Table 5.1: Flood-prone land use in the study area

(Source: VICMAP and Melbourne water data)

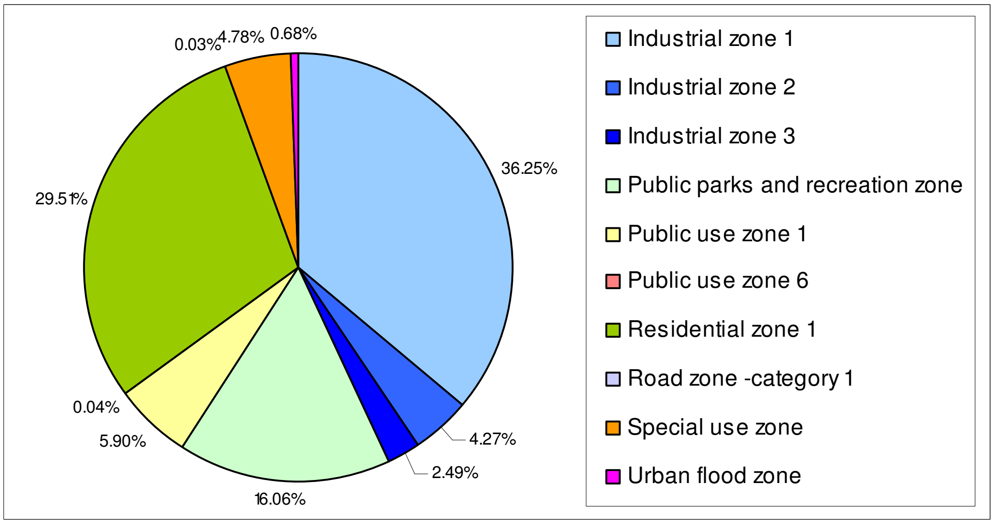

Figure 5-5: Flood-prone land use in the study area

(Source: VICMAP and Melbourne Water data)

5.5 SETTLEMENT HISTORY AND BUILDING PATTERN

European settlement in the area started in Sunshine, originally a settlement of Aborigines, in the early 19th century. In the late 19th century, it became a crucial town as it was the junction of the railroads that joined Melbourne, the port of Williamstown and Newport and the gold mining areas such as Bendigo and Ballarat. The settlement of Albion began after Sunshine in 1850 but there were only a few houses developed before the 1920's. Ardeer's settlement began after World War II in the 1950's. Settlement of the south-eastern part of Kororoit Creek, Sunshine West, began in 1900 but it had a slower development compared to Sunshine. Brooklyn, south of Sunshine began as an industrial area after World War II (Ford 2001).

In terms of style and building materials, residential houses in the early settlement period (1800-1900) in this study area were built using bricks, stones and tiles which were replaced by wood and corrugated iron (federation-style) in the early 1900s. In the period between 1970 and 1990, ordinary looking brick and tile buildings began to be replaced by the federation-style houses. In recent times, the houses have become double storey flats with modern architecture, but still using the same materials as used in the period between 1970 and 1990: bricks and tiles (Ayton 2005). Figure 5.4 shows the styles of residential houses from different eras in the study area.

House built in early 1900 | House built in 1970's | House built in recent years

Figure 5-7: Styles of residential houses from different eras in the study area.

Source: Field Survey, November 2007

5.6 DEMOGRAPHY

Areas with a high population density are more prone to flood damage. There are more than 30,000 people living in the five suburbs of the study area (ABS 2006a). Among the suburbs, Sunshine West has the highest population density (followed by Sunshine, Albion and Ardeer) and features one of the most ethnically diverse populations in the world. Compared to other suburbs, Brooklyn is basically an industrial area with only a few blocks of residential properties and therefore has the lowest population density

Table 5.2 shows the population, area size, population density, and mean household income of the five suburbs in the study area. The mean household income ranges from $680 to $769, which is much lower than the Australian average of $1024. Mean household income is useful for determining an estimate of the metre square replacement value for residential buildings and in presuming the contents value. Mean household income is usually estimated through the residential building valuation process which was discussed in Chapter 4. Data on mean household income on a property basis can be retrieved from the NEXIS database developed by Geoscience Australia. (See Chapter 6 for more details on the NEXIS database, and Table A.1 and its corresponding section in Appendix A discusses for how the mean household income and other building features are calculated in NEXIS database.)

. Suburb	Population (person)	Area (sq km)	Population Density (person per sq km)	Mean Household Income (dollar per week)
Sunshine	8070	4.9	1646	738
Sunshine West	15906	7.9	2013	769
Albion	3763	2.5	1505	680
Ardeer	2582	2.1	1229	680
Brooklyn	1583	5.2	304	717

Table 5.2: Population, area, population density and mean household income of the five suburbs in the study area

Source: ABS (2006a)

5.7 HISTORY OF FLOOD

The Kororoit Creek floodplain is inundated frequently by floods of a few centimetres to a few metres in depth. Among the floods that have occurred, the 1917 flood was the most severe (flooding up to few metres in depth) and is considered as a centennial flood (i.e. its chance of occurrence is once in a hundred years). The second most severe flood occurred in 1983. Other big floods along the Kororoit Creek occurred in 1946, 1950, 1977 and 1985 (MWRC 1984). Figure 5.5 shows the flood along the Kororoit Creek at Sunshine in 1946.

Figure 5-9: 1946 Flood in Sunshine caused by Kororoit Creek

Source: (Museum Victoria 2001)

5.8 CONCLUSION

The aim of this study is to develop and demonstrate a GIS based approach to economic assessment of residential flood damage at property level. For this purpose, a segment of Kororoit Creek and its adjacent area has been chosen as the study area. The previous sections of the chapter have discussed various aspects of the study area which include location, geomorphology, uses of flood-prone land, demography, settlement and building pattern and flood history. These aspects of the study area help the implementation and demonstration of the method discussed in chapter 4.

The next chapter discusses, in detail, the process of implementing the method to the study area and on results derived from the process, including data collection, flood modelling, identification of flood-prone properties, building inventory, stage-damage curves, damage measuring and result validation.

CHAPTER 6:

ECONOMIC ASSESSMENT OF RESIDENTIAL FLOOD DAMAGE

6.1 INTRODUCTION

Chapter 4 discussed the framework of economic loss assessment for this study, including five main analytical procedures: flood surface mapping, building inventory, stage-damage curves adoption, measuring damage and results validation. Chapter 5 described briefly the case study area in terms of its location, geomorphology, uses of flood-prone land, demography, settlement history and building pattern, and flood history. This chapter discusses in detail the procedures the study deployed and the implementation of the procedures for estimating residential flood damage using datasets of the study area. The discussion is carried out in the following sequence:

- Data collection,
- Mapping flood surfaces,
- Conducting building inventory,
- Adopting stage-damage curves,
- Measuring Damages, and
- Validating Results

6.2 DATA COLLECTION

Data sets relevant to flood surface mapping, building inventory and stage-damage curves adoption have been collected from different sources for the study area, as shown in Table 6.1. These data sets are indispensable for carrying out, for the study area, the activities of flood surface mapping, building inventory, stage-damage curves adoption, flood damages measuring and results validation.

Step of the analysis	Data	Description of data	Sources	Format	Comments
1. Flood modelling	Flood extent boundary	Showing the extent of a 100 year flood event	Melbourne Water	Polygon shapes	Derived from flood model analysis and surveyed data in 1997; scale of the source map is 1:2K
	Flood level cut line	A set of lines across the river showing the level of a 100 year flood	Melbourne Water	Polyline shapes attributed with flood level values	Derived from flood model analysis and surveyed data in 1997; scale unknown
	Elevation contour	One metre interval contour lines of ground surface	VicMap	Polyline shapes attributed with elevation values	1:10k
	Stream network	Showing geometric details and topological connections of the links and joints of the stream network	VicMap	Polyline shapes attributed with stream name	1:25k
2. Building inventory	Building occupancy	Property level data of building occupancy	NEXIS and field survey	Attributes along with point shape file	Property level information

Step of the analysis	Data	Description of data	Sources	Format	Comments
	Building replacement value	Square metre replacement value of different types of buildings	Cordell and NEXIS	Attribute values classified as numeric	Derived from insurance company website and NEXIS dataset
	Depreciation model	A graph or table showing depreciated value of buildings in relation to building age	HAZUS and BTE	Graph and table	HAZUS is an USA model where BTE is an Australian model
	Floor space	Floor space of the buildings in each property	Extracted from Sensis aerial photo and NEXIS	Polygon shapes attributed with square metres of floor space	Data from both sources are compared, and the reasonable one is used
	Age	Age of the buildings	Field survey	Attribute values classified as numeric	Photos were taken to assess age of the buildings; property level information
	Number of storeys	Number of storeys in the buildings	Field survey	Attributes classified numeric	Field survey 2007, property level information
	Building material used	Material used to construct the buildings	NEXIS, field survey	Attributes for floor, wall and roof material along with point shape file	Property level information
	Household income	Average household income	NEXIS, ABS	Attributes along with point shape file	ABS data is compared with NEXIS data; property level information
	Contents value	Total value in each property other than building structure	NEXIS	Attributes along with point shape file	NEXIS estimated contents value on the household income; Property level information
3. Stage-damage curves	Stage-damage curve for structure	A graph or table showing structure losses in relation to flood depth	HAZUS and NHRC	Attribute values shown in tables and graphs	Data from both sources are compared, and the reasonable one is used
	Stage-damage curve for contents	A graph or table showing contents losses in relation to flood depth	HAZUS and NHRC	Attribute values shown in tables and graphs	Data from both sources are compared, and the reasonable one is used

Table 6.1: Datasets for mapping flood surface.

6.3 MAPPING FLOOD SURFACES AND IDENTIFYING FLOOD-PRONE PROPERTIES

A flood surface is derived from a set of flood water levels within a specific flood extent of a given flooding event. During a flooding event, flood water level varies temporarily at a given location and spatially within a specific flood extent. Conceptually, a flood surface may be defined for any moment during a flooding event. But practically, a flood surface can only be approximated for the flood extent that is identifiable in some ways. The maximum flood extent is usually identifiable in the field immediately after the flood water has retreated.

In this study, mapping a flood surface refers to the process of interpolating a flood surface using flood levels derived from a set of flood level cut lines within the 100 year flood extent.

Flood surfaces of individual reaches are interpolated separately and are then merged to form a continuous flood surface for the study area. The maximum flood depth across the 100 year flood extent can be derived by subtracting the land surface elevation from this merged flood surface. Mapping flood surface for an individual reach involves the following steps: (1) define a flood extent; (2) extract the centre line; (3) create a set of flow corridor lines; (4) generate regularly spaced point flood level information; and (5) derive surfaces of flood level and flood depth. The datasets collected for mapping flood surfaces is reviewed in Section 6.3.1.

6.3.1 Data for mapping flood surfaces

Data sets on flood extents, flood levels, ground surface elevations, and stream networks are needed for flood surface mapping. Firstly, boundaries of flood extents are usually represented as polygon shapes. As the study deals only with probable maximum flood, only the extent of the 100 year flood extent of Kororoit Creek is collected. The data was generated from a hydrological survey and analysis conducted by Melbourne Water in 1997 (MW 2007a). Secondly, flood levels are usually represented as straight parallel lines (known as flood level cut lines) by means of polyline shapes representing the flood height at different sections of the streams. The 100 year flood level cut lines have been collected for Kororoit Creek. The flood level cut lines are derived from river gauge information, hydrological surveys and analysis conducted by Melbourne Water in 1997 (MW 2007b). Thirdly, flood surface mapping requires a Digital Elevation Model (DEM) to determine flood depth. A high fidelity DEM can produce precise flood depth surfaces and more accurate damage estimation. Contours of 1 metre interval were collected and a 1 metre resolution DEM developed from these contours for the study area. The contours are represented as polyline shapes digitized from the 1:2500 scale used in the Melbourne Water base maps (NRE 2004a). Data on the stream network is required to compare the centreline of the flood extent derived from the study procedures. The stream network data available for the study area is represented as polyline shapes digitized from 1:10,000 or 1:25,000 scale base maps (NRE 2004b).

6.3.2 Defining a flood extent

The 100 year flood extent for an individual reach is defined by the intersection of the upstream and downstream extent of the reach and the 100 year flood boundary, as shown in Figure 6.1.

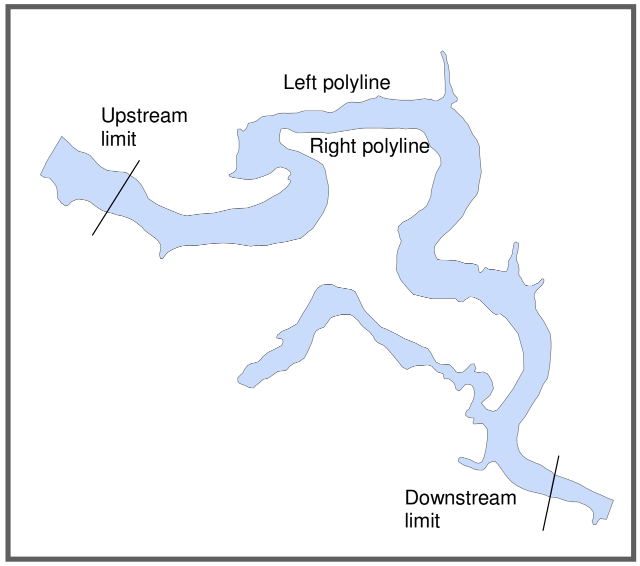

Figure 6-1: Delineation of flood extent

Each flood extent should be defined by exactly 4 polylines – one for the upstream limit, one for the downstream limit, one for the boundary of 100 year flood extent on the left, and one for the boundary of 100 year flood extent on the right, flipping the left and right polylines is necessary to ensure they point from the upstream to downstream direction. Any holes or islands should be removed from the defined flood extent.

6.3.3 Delineating the centreline

The centreline of a defined flood extent can be conceptualised as the path of the centre of an imagined circle moved from the upstream limit to the downstream limit. The circle centred initially somewhere on the upstream limit with a radius that touches the right and left flood extent boundaries. The circle is moved through the reach with the radius changing according to the width of the flood extent to ensure that it always touches the right and left flood extent boundaries until it reaches the downstream limit. Tributaries and backwater areas are usually excluded to ensure a smooth flood extent boundary and hence a smooth centreline. A backwater area is where the elevation is the same as the elevation of the main stream and no water flows from there to the main stream (Leigh et al. 2001).

The following steps are used in the study to extract the centreline: (1) ensure that the upstream and downstream polylines are snapped to the left and right polylines and all polylines (including upstream and downstream limits as well as left and right polylines) point in the same direction; (2) convert the four polylines into a flood extent polygon; (3) generalise the 1 m DEM into a 5 m DEM (as it is easier to handle a coarse resolution DEM); (3) clip the 5 m DEM using the flood extent polygon; (4) convert the clipped 5 m DEM into a set of square polygons; (5) populate a field in the square polygons with the identification number of the nearest polyline of the flood extent boundary; (6) merge the square polygons into two big polygons using the information of the left and right flood extent boundaries; (7) convert the merged polygons into polylines and take the common border of them as the centreline of the flood extent (9) smooth the centreline if necessary; (10) stream network is used as a reference to refine the centreline.

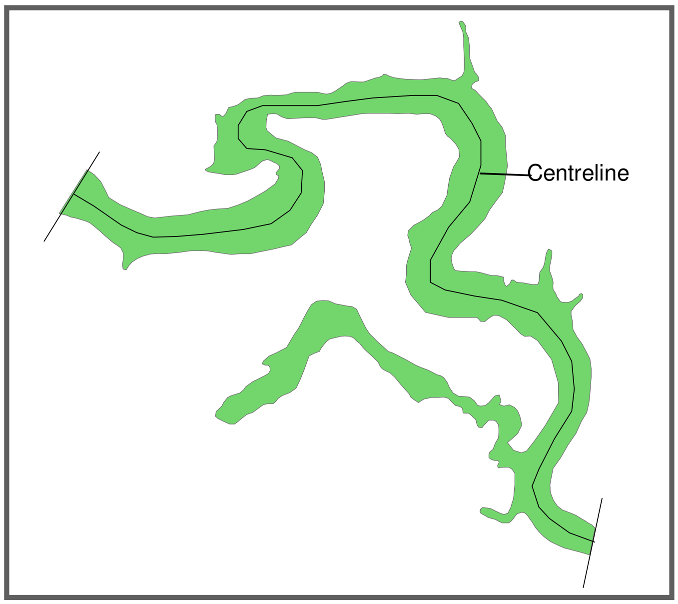

Figure 6-3: Centreline of the flood extent

6.3.4 Creating flow corridor lines

Flow corridor lines are lines that are parallel to, and within a set of specified distances from the delineated centreline of the flood extent. Flood corridor lines are used to extract or interpolate regularly spaced flood levels from a set of flood level cut lines.

A set of flow corridor lines is created for each defined flood extent by the following procedures: (**1**) create a buffer on the delineated centreline which covers most of the area of the floodplain except tributaries and backwater areas, as shown in Figure 6.3; (**2**) convert the buffer into polylines; (**3**) extend the upstream and downstream limits to the buffer polylines; (**4**) clip buffer polylines that exceed the upstream and downstream limits; (**5**) generate a set of buffers on the centreline using an incremental distance equal to the resolution of the DEM (that is 1 m), with the last buffer touching the buffer polylines created in step (1); (**6**) repeat steps (2) to (4) for all the buffers created in step (5); (**7**) extend all available flood level cut lines to the outermost buffer polylines and intersect them with all the buffer polylines, as shown in Figure 6.4.

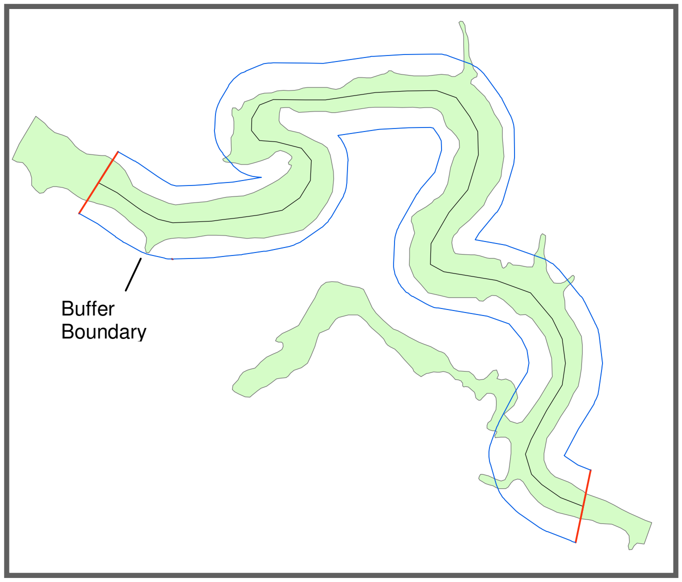

Figure 6-5: Buffer to cover the flood extent

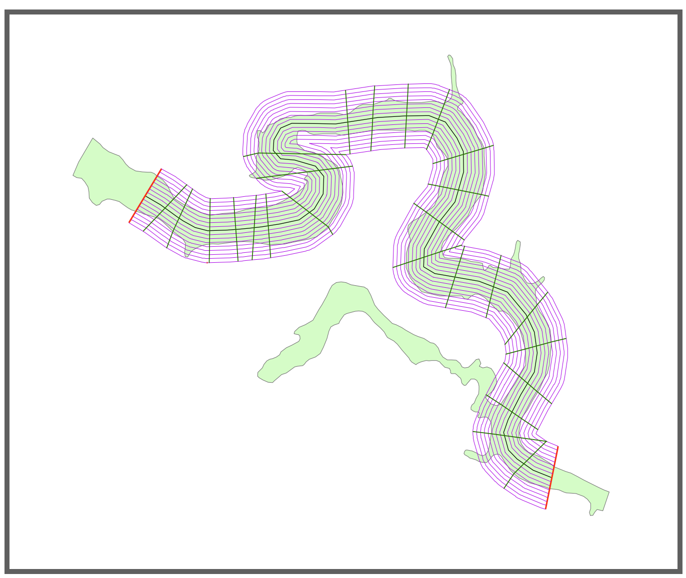

Figure 6-7: Flow corridor lines created at the interval of DEM cell size

6.3.5 Generating point flood level information

A set of regularly spaced point flood level data is needed to interpolate a flood surface. Generally speaking, this information is transferred from the available flood level cut lines to a set of points evenly spaced along the flow corridor lines by means of flood level arcs and linear interpolation. A flow corridor line is intersected by a set of flood level arcs, with each flood level arc bound by two flood level cut lines: one upstream and one downstream. These flood level arcs are segmented further into small arcs, and flood level information from flood level cut lines are transferred to the upstream vertices of these small arcs by means of linear interpolation. The regularly spaced vertices with assigned flood level information can be used to generate a flood surface.

The following procedures are used in this study to generate a set of regularly spaced point flood level data for a flood extent: (**1**) ensure all flow corridor lines point in the downstream direction; (**2**) densify all flow corridor lines with a tolerance of one metre, equal to the resolution of the DEM; (**3**) intersect all flow corridor lines with all available flood level cut lines – this operation splits each flow corridor line into a set of flood level arcs, and each flood level arc is bounded by two nodes: one is the intersection with the upstream flood level cut line and the other with the downstream flood level cut line; (**4**)Convert the flood level arcs into flood level points at their vertices; (**5**) calculate the flood level at each point on the basis of flood information of upstream and downstream cut lines and the distance between the point and the cut lines – if a point is closer to a upstream cut line than a downstream cut line, the upstream cut line will have more influence than the downstream cut line to determine flood level of the point. Figures 6.5 and 6.6 show the flood level points.

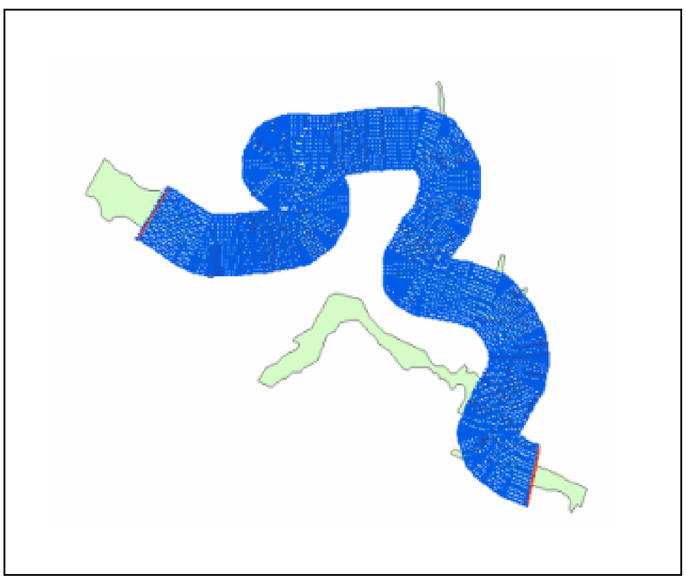

Figure 6-9: Points at one metre interval contain flood level information

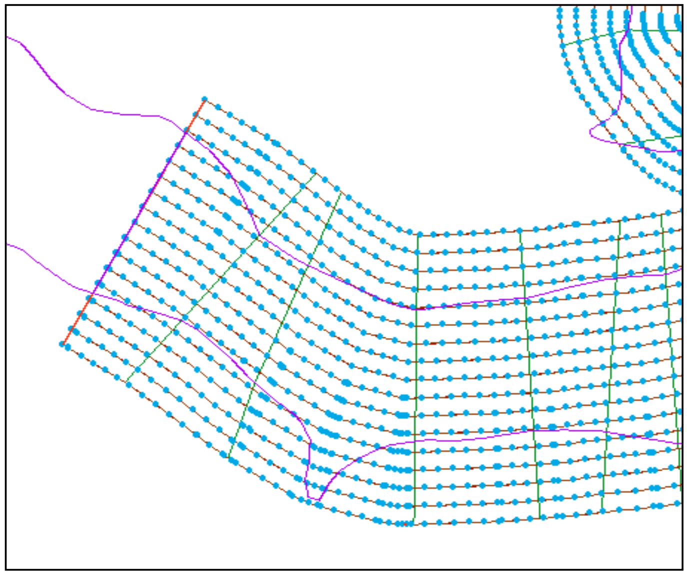

Figure 6-11: Points at one metre interval contain flood level information (magnified)

6.3.6 Deriving flood depth information

Information on flood depth can be derived from information of flood level and ground elevation. In this study, the following steps are followed to derive flood depths within a flood extent: (1) convert the regularly spaced point flood levels into a flood surface grid using the assigned flood levels as the elevation of the flood surface; (2) derive the flood depth surface by subtracting the ground elevation surface from the flood level surface.

The ground elevation surface for the study area is represented by a 1 metre DEM generated from 1 meter interval contours. Surfaces of flood depth for the six reaches in the study area are shown in Figures 6.7 to 6.12; with a flood depth range from 0 m to 6.29 m. In Section 6.6.1 both the flood level data and the flood depth data derived will be used for measuring floods at buildings relative to their ground floor height.

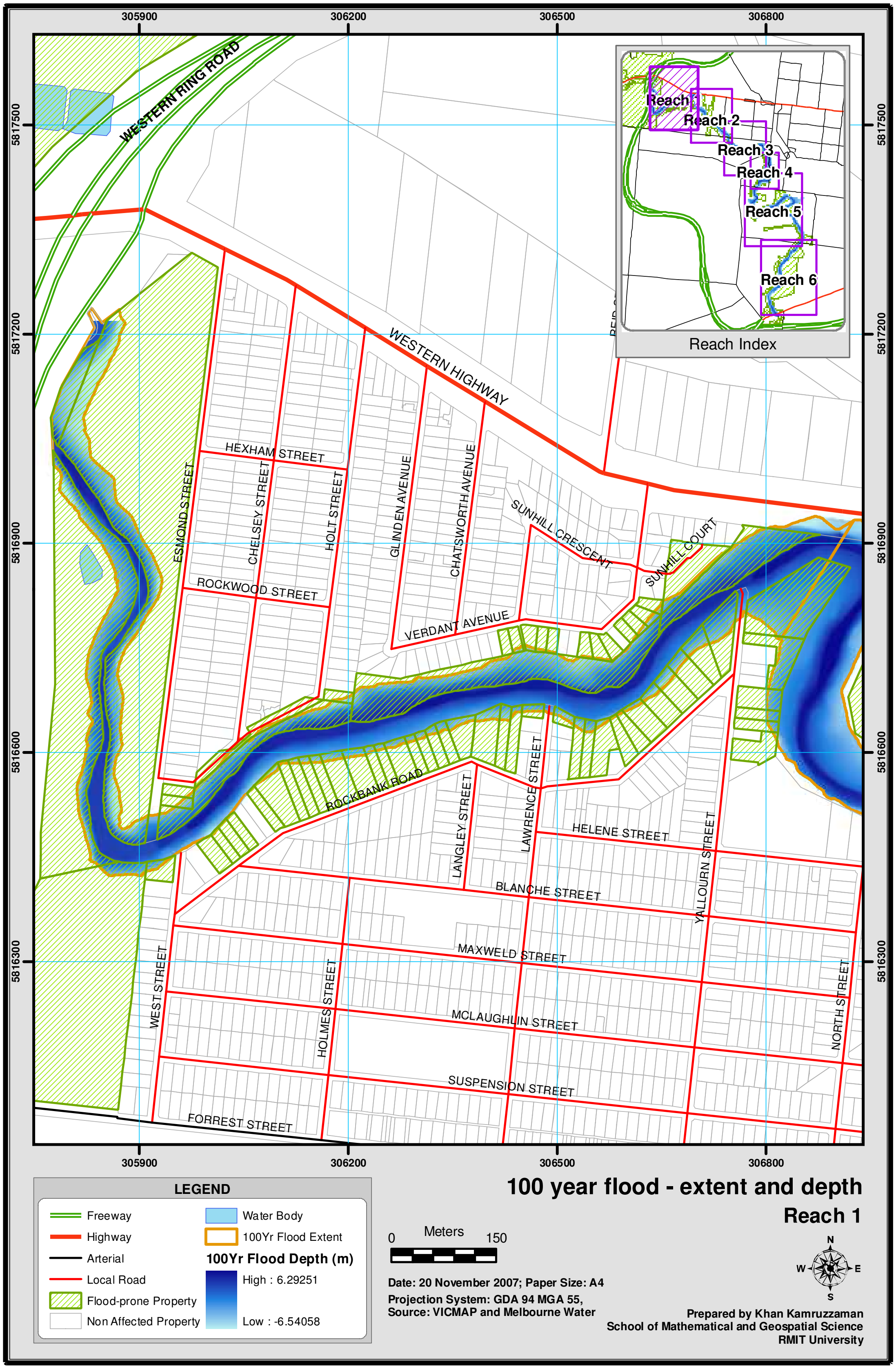

Figure 6-13: 100 year flood – extent and depth for reach 1

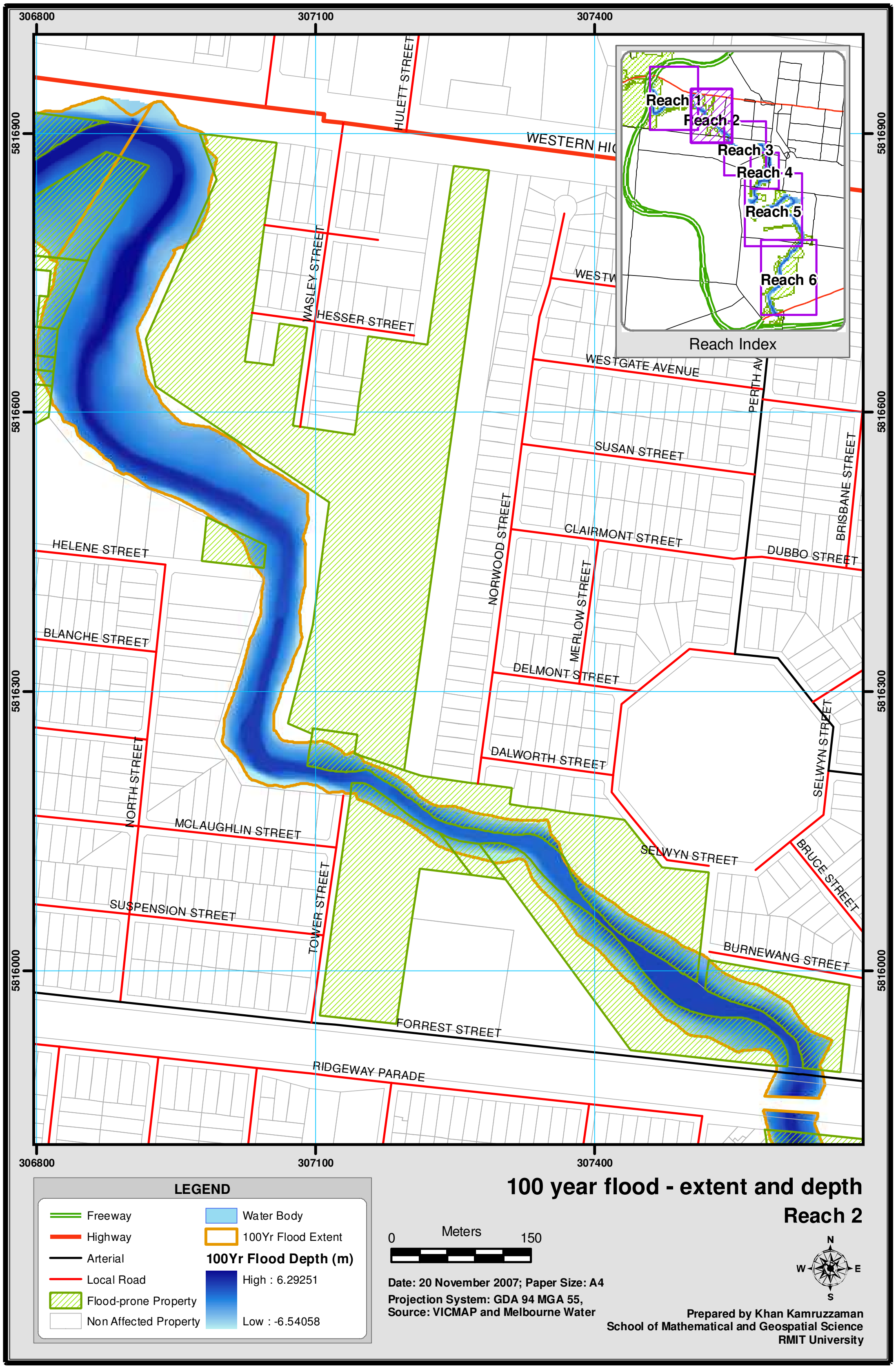

Figure 6-15: 100 year flood – extent and depth for reach 2

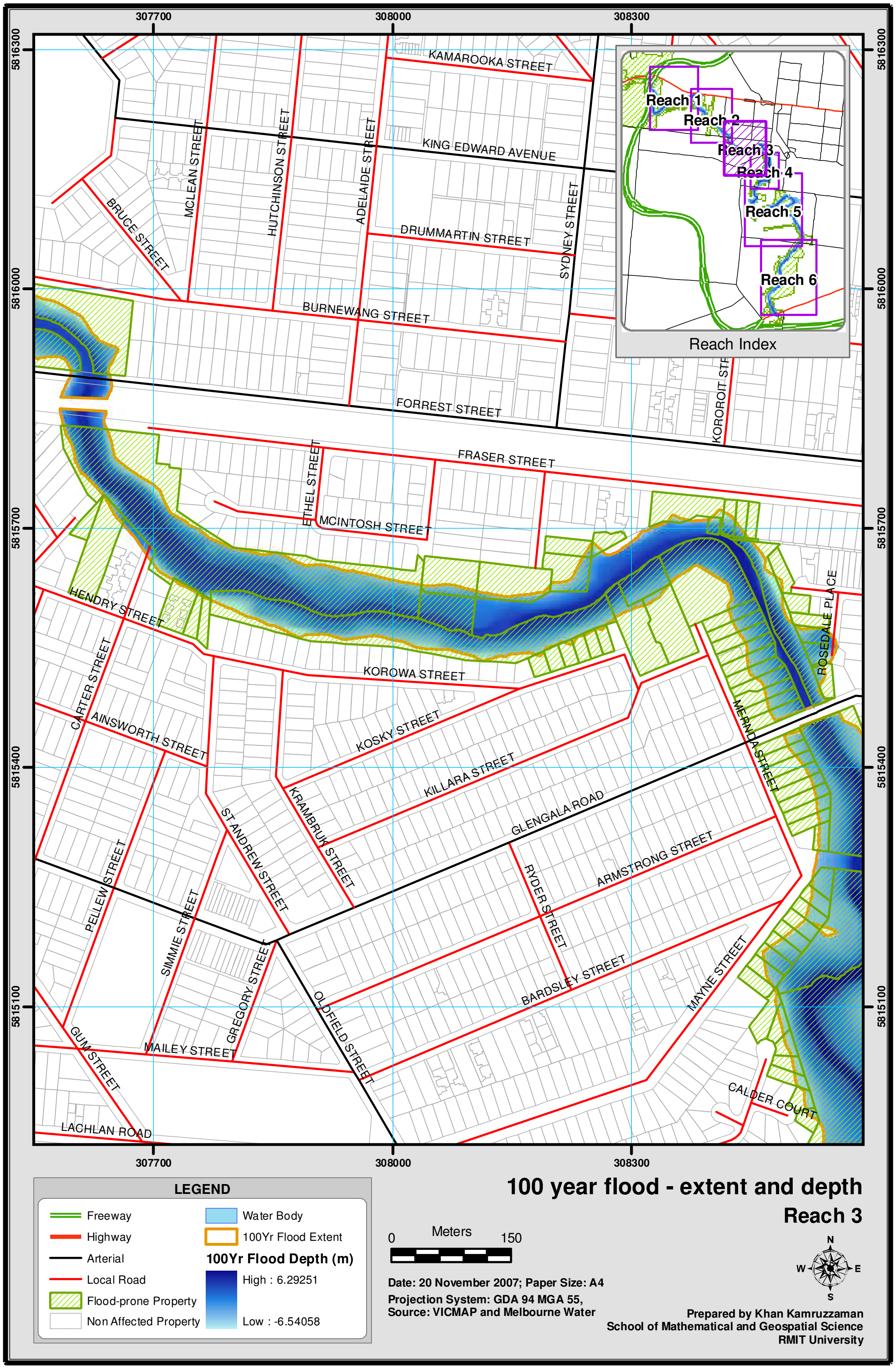

Figure 6-17: 100 year flood – extent and depth for reach 3

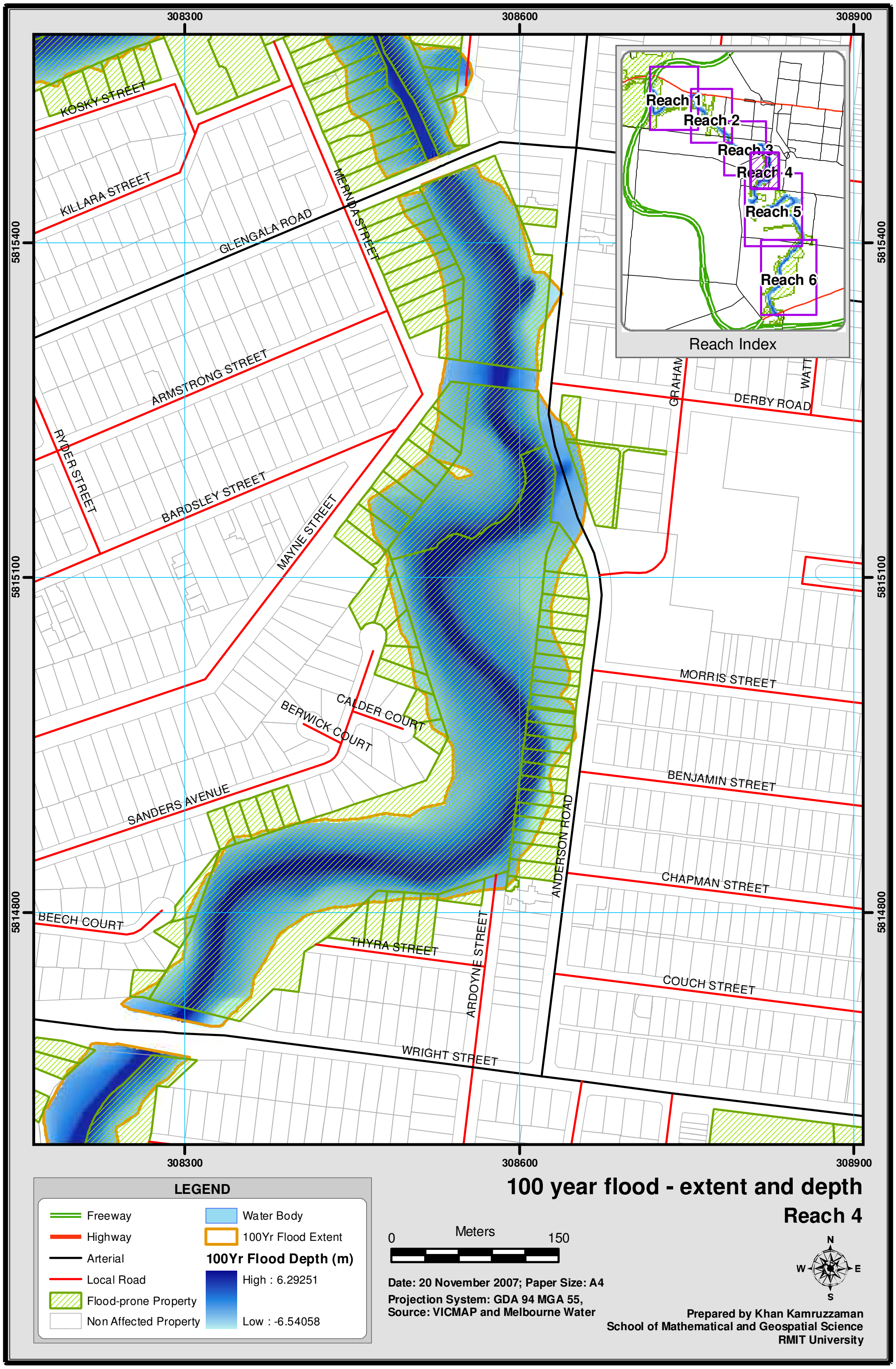

Figure 6-19: 100 year flood – extent and depth for reach 4

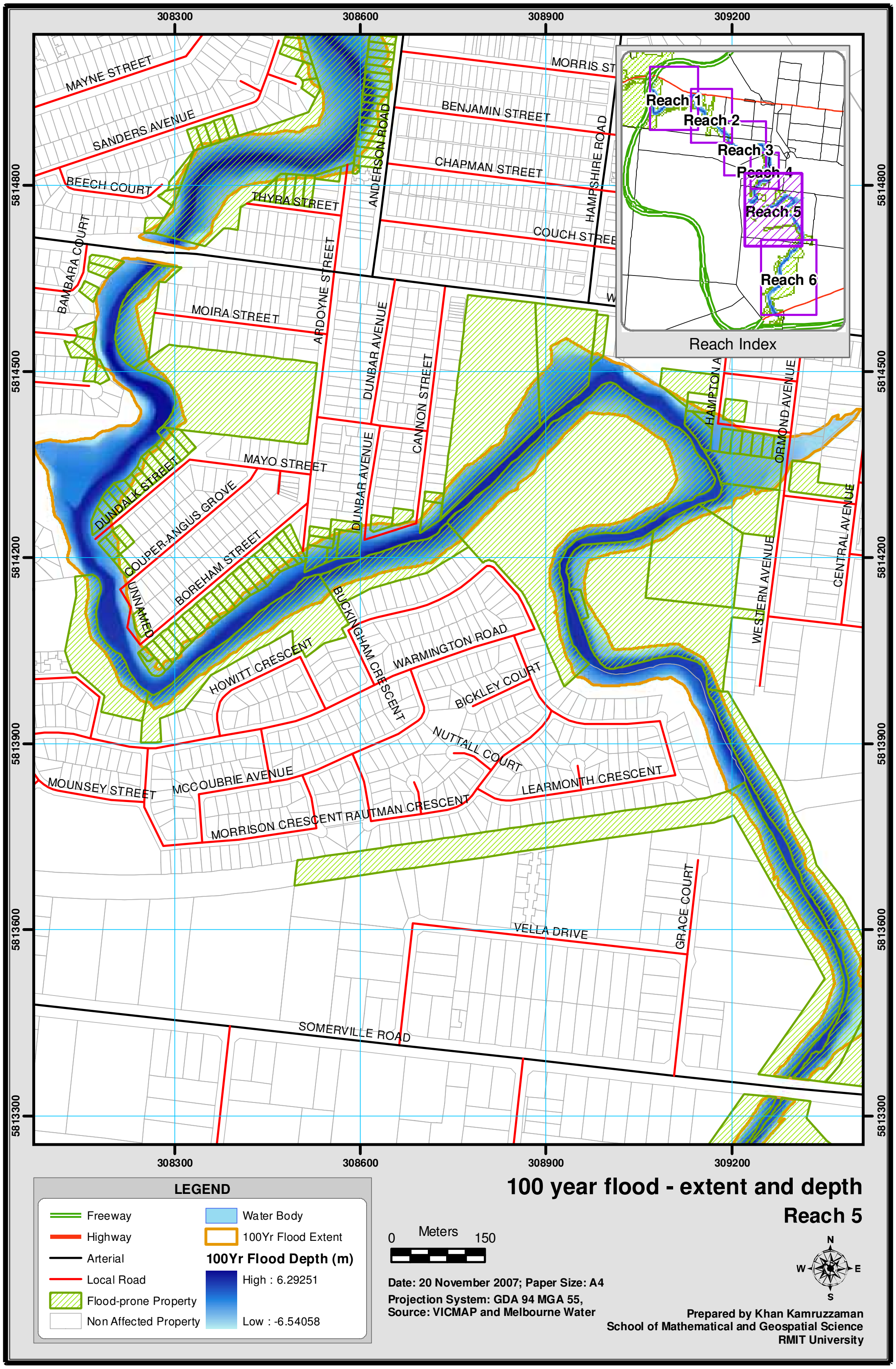

Figure 6-21: 100 year flood – extent and depth for reach 5

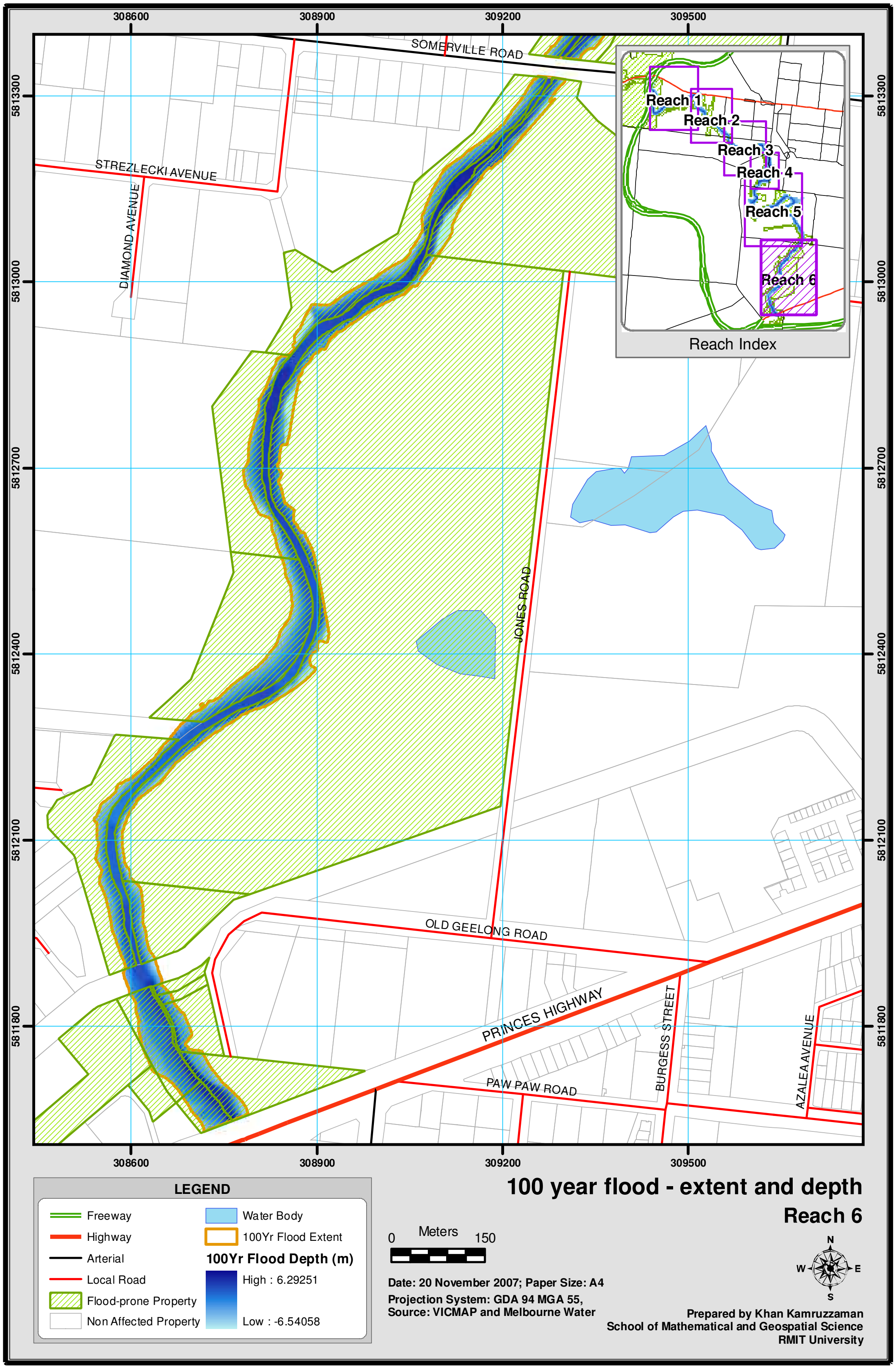

Figure 6-23: 100 year flood – extent and depth for reach 6

6.3.7 Identifying flood-prone residential properties

Residential properties prone to a 100 year flood event need to be identified to assist other activities in the methodology such as building inventory, adopting stage-damage curves, measuring damage, and validating results.

In this study, the following procedure is used to prepare datasets on flood-prone residential properties and buildings: (1) select residential properties from the land use data layer; (2) overlay the selected residential properties with a 100 year flood extent of Kororoit Creek; (3) select all properties intersected by the flood extent polygon – a total of 191 flood-prone residential properties were identified, as shown in Figure 6.14; (4) key attributes for both the property level and the building level are identified and clarified, as shown in Figure 6.13.

Property shape file

Analysis step	Field name	Field description
Building Inventory	Prop_ID	Unique identification number
	BF_Area	Total floor space in metre for all buildings counted in the property
	No_Story	Number of story of the building
	Blg_Age	Age of building
	BO_Class	Building occupancy class
	Roof_Type	Materials used to construct the building roof
	Wall_Type	Materials used to construct the building wall
	Floor_Type	Materials used to construct the building floor
	Inc_Group	House income
	Blg_Cost	Cordell square metre cost informaton
	Blg_Value	Building replacement value
	Depre_Per	Depreciated value of the building in percent
	Depre_Val	Depreciated value of the building in dollar
	Blg_Ec_Val	Building economic value
	Cnt_Value	Content value
Adopting stage-damage curve	DmgCrv_Used	Stage-damage curve applied
Measuring damage	Flood_Depth	Average flood depth of the buildings at property
	SDmg_Per	Structure damage in percentage
	SDmg_Doll	Structure damage in dollar
	CDmg_Per	Content damage in percent
	CDmg_Doll	Content damage in dollar
	TDmg_Doll	Total damage in dollar

Building shape file

Field name	Field description
BF_Area	Floor space in square metre
Blg_ID	Unique identification number
Floor_Lvl	Ground floor height in metre above AHD
Flood_Lvl	Flood level height in metre above AHD
Flood_Depth	Flood depth in metre relative to ground floor height

Figure 6-25: Key attributes identified for flood-prone residential properties and buildings

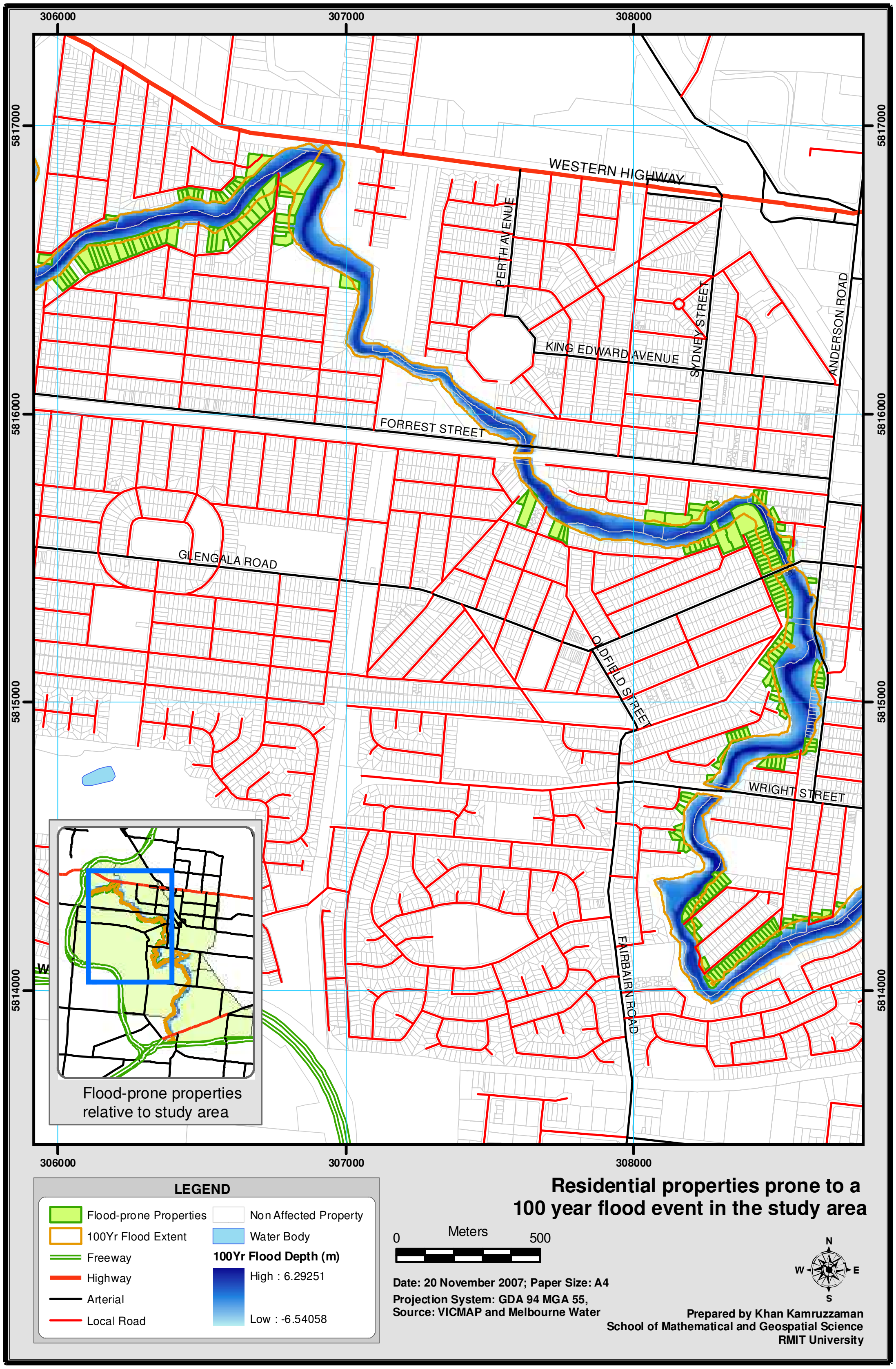

Figure 6-27: Residential properties prone to a 100 year flood event in the study area.

6.4 CONDUCTING BUILDING INVENTORY

In a building inventory, data collected for a building usually includes the following items: building occupancy classes, number of storeys, floor space, materials used for constructing the building, household income, building replacement value, age of the building, depreciation building replacement cost, ground floor height, and contents value.

6.4.1 Building occupancy classes

The information on occupancy classes of buildings helps in selecting the appropriate stage-damage curves to be applied. The NEXIS dataset (National Exposure Information System) is the main information source for building occupancy classes. More discussion on the NEXIS dataset will be given in Appendix A. Occupancy classes taken from the NEXIS dataset are reasonably accurate at property level, according to data collected from field surveys.

Two renowned models for flood loss assessment, ANUFLOOD and HAZUS, have classification of building occupancy. ANUFLOOD, developed by the Centre for Resource and Environmental Studies at the Australian National University (Thompson and Handmer 1996), has 19 classes of building occupancy, with 3 classes for residential building (Reed Sturgess and Associates 2000). HAZUS has 33 classes of building occupancy, with 6 classes for residential building. HAZUS was first developed in 1995 and it is continuously being updated with new information and adopted to new circumstances (FEMA 2003). This study follows the basic principles of HAZUS in classifying occupancies of properties. In addition, ABS (Australia Bureau of Statistic) conducted housing surveys in 1998 based on the HAZUS classes (GA 2006).

Table 6.2 shows the occupancy classes of residential buildings which are based on the HAZUS model as well as ABS classification of building occupancy. In Table 6.2, residential buildings are divided into 6 classes such as single family detached-building (RES1), mobile house (RES2), multi family house (RES3), temporary lodging (RES4), long time lodging (RES5) and nursing home (RES6). Among them the multi family dwelling (RES3) has a wide range: 2 to 50 family units. Therefore, it has been divided into sub-classes such as RES3A, RES3B, RES3C, RES3D, RES3E and RES3F on the basis of the number of units. The reason of this subdivision is because the damage scenario varies widely between the number of dwelling units in a multi family building.

Occupancy class code		Occupancy class name	Description	Example
RES1		Single family dwelling	A house which stands alone on its own ground and is separated from other dwelling.	Separate house or detached house
RES2		Mobile house	A house which is not permanently built on ground	Caravan, Cabin or houseboat.
RES3	RES3A	Multi family dwelling – Duplex	Semi-detached two dwelling units which share a common wall and their sizes are usually same as a normal single family dwelling.	Duplex house
	RES3B	Multi family dwelling – 2-4 units	Attached, semi-attached or sole occupancy dwellings which might or might not have own private grounds.	Row, terrace house, townhouse, flat, unit or apartment.
	RES3C	Multi family dwelling – 5-9 units	Same as RES3B	Same as RES3B
	RES3D	Multi family dwelling – 10-19 units	Same as RES3B	Same as RES3B
	RES3E	Multi family dwelling – 20-49 units	Same as RES3B	Same as RES3B
	RES3F	Multi family dwelling – 50+ units	Same as RES3B	Same as RES3B
RES4		Temporary lodging	A dwelling for sort time stay	Hotel, motel or hostel
RES5		Long time lodging	A dwelling for long time stay	Guesthouse, residential part of an institute, shop, office or factory
RES6		Nursing home		Nursing home and aged care centre

Table 6.2: Occupancy classes of residential buildings in Australia

Source: ABS 2006a; Dhu and Jones 200

The flood-prone properties in the study area fall into 4 occupancy classes: RES1, RES3A, RES3B and RES3C. The field 'BO_Class' of the property table provided in Appendix D shows the building occupancy of buildings in flood-prone properties.

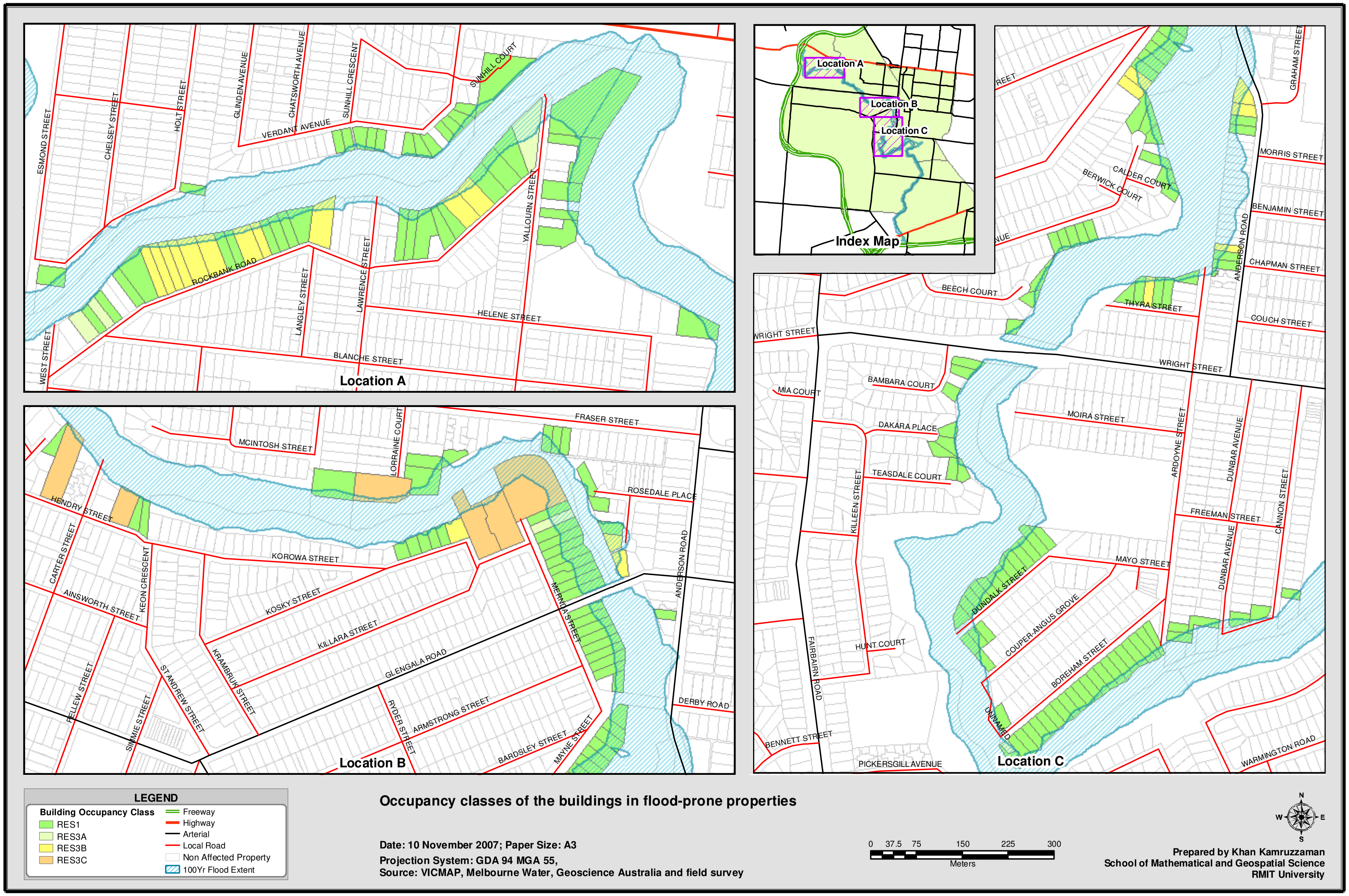

Figure 6-29: Occupancy classes of the buildings on flood-prone properties

6.4.2 Number of storeys

Data on the number of storeys in buildings is collected in field surveys. The number of storeys of a building is needed to estimate the floor space. For a multi-storey building, the floor space calculated from the building footprint (as discussed in Section 6.4.3) is multiplied by the number of storeys to get a total floor space of the building. The storey information is also needed to identify an appropriate stage-damage curve for damage estimation. Stage-damage curves are categorised on the basis of the number of storeys, as a 1 storey building will be subjected to more damage per floor area than a multi-storey building. Floods usually cause significant damage on the ground floor rather than the floors above it. Therefore, a range of stage-damage curves have been used for different buildings with different numbers of floors to obtain precise damage estimation. In the study area, there are both single and double storey buildings. Most of the buildings are single storey buildings, with only 21 out of 191 buildings being double storey. The field 'No_Storey' of the property table provided in Appendix D shows the number of storeys of buildings in flood-prone properties. Figure 6.16 also shows the spatial distribution of buildings in the study area with reference to the number of storeys they have.

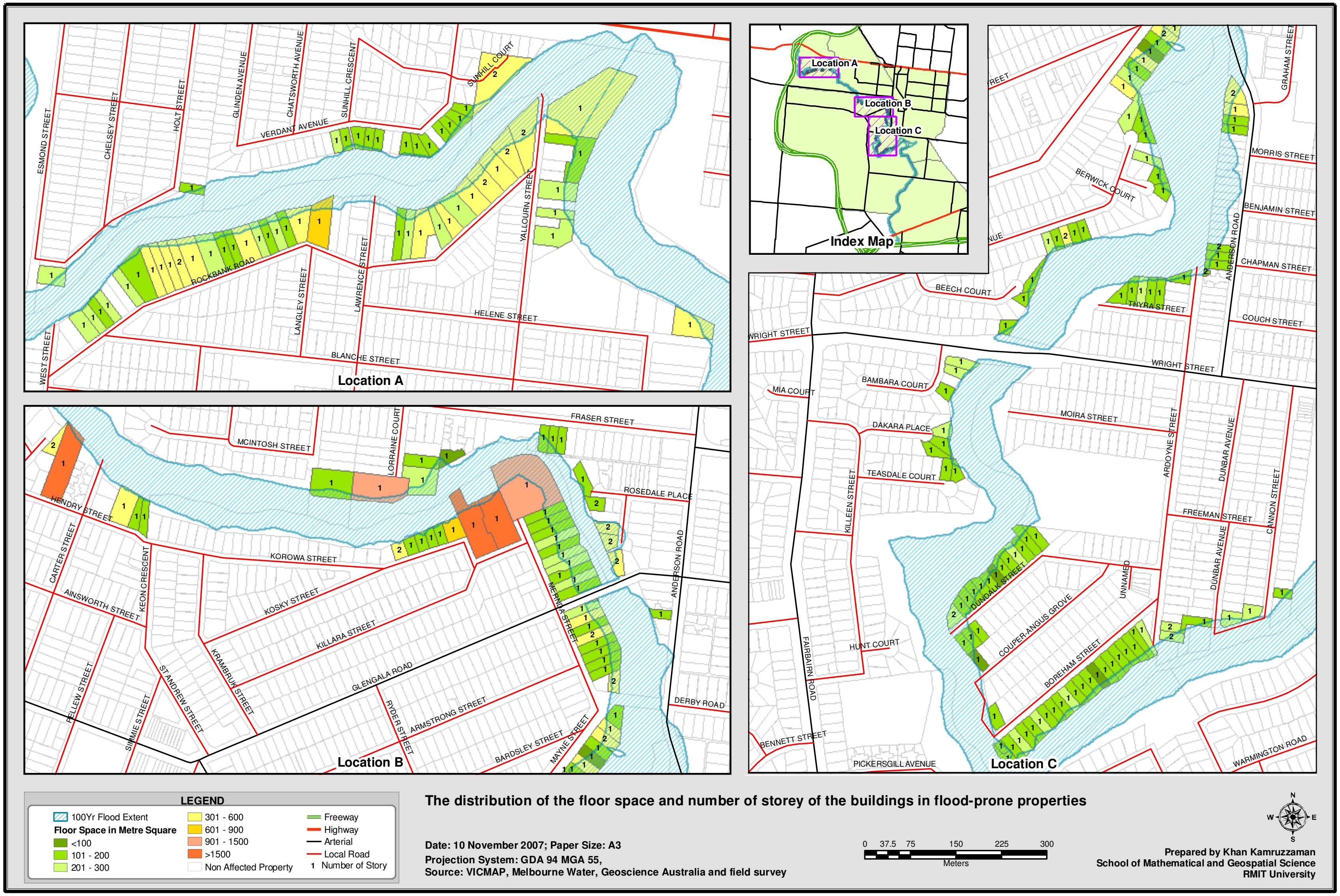

Figure 6-31: Distribution of floor space and number of storeys of buildings on flood-prone properties

6.4.3 Floor space

Floor space data represents the total floor area, in square metres, of all buildings in a property. The floor space of a building is needed to estimate the building replacement value. The floor space of each building is calculated in square metres by multiplying the floor space with the square metre rate of building replacement value. The NEXIS data includes floor space information for properties. The data was derived from Housing Survey information conducted by ABS in 1998 which is more accurate on the broader scale than on the property level (Nadimpalli et al. 2007). The floor space at property level needs to be as accurate as possible as it is used to place a value on buildings which is the main factor in the cost of damage. In this study, the floor space value is calculated from the building footprint extracted from fine resolution aerial photos. Floor space information from the NEXIS dataset is used for verifying the calculated floor space.

High resolution aerial photographs from Google Earth and Sensis websites for the study area are used to delineate building footprints. The picture resolution is 15 cm for Sensis photos (Sensis 2007), and 35 cm for Google Earth photos (DigitalGlobe 2007). Sensis photos are used for delineating building footprints, and Google Earth photos are used when confusions arise in identifying any features in the photos. Figure 4.11 shows two sample photos.

Aerial photo from Google Earth | Aerial photo from Sensis

Figure 6-33: Comparison between aerial photos from Google Earth and Sensis

About 50 aerial photo snapshots of the whole study area have been downloaded from the Sensis website. These snapshots are combined into one photo mosaic using Adobe Photoshop (version 6). The photo mosaic is then rectified with road shapes in ArcGIS. The building roofs or tops shown in the rectified photo mosaic are digitised as the footprints of buildings. Figure 6.18 shows building footprints delineated from the Sensis photo mosaic.

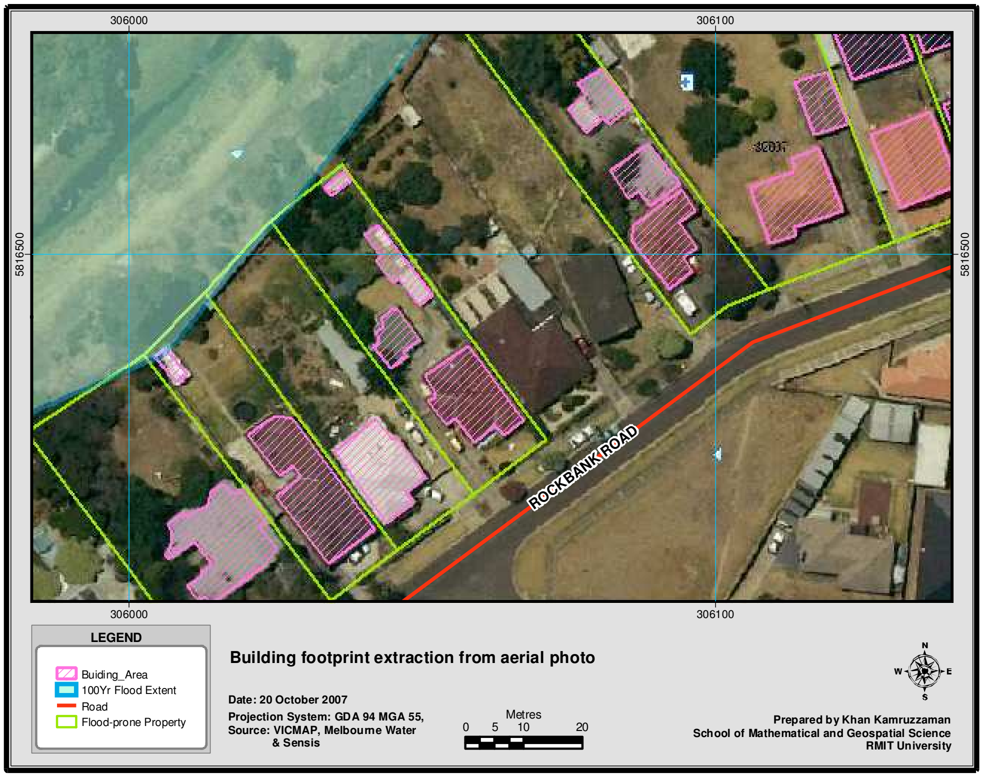

Figure 6-35: Delineation of building footprint from Sensis aerial photo

In general, the roof area is bigger than the floor area of a building. Therefore, a 0.5 metre buffer is created inside the delineated building footprints. Sheds and garages normally have the same roof area as floor area so these have been excluded from the buffer analysis. Finally, the area of the floor has been calculated from the footprints in square metres. The field ‘BF_Class’ of the property table provided in Appendix D shows the floor space of buildings in flood-prone properties. Figure 6.16 also shows the distribution of floor space in the study area.

6.4.4 Materials used for constructing buildings

Data on the materials used to construct buildings in the study area, including the materials used for constructing the floor, wall and roof of the buildings are sourced mainly from the NEXIS dataset, and verified with photos of the buildings taken during the field survey. Data on materials used to construct buildings is needed to determine the appropriate building class and mean replacement cost per square metre as described in Tables 6.3 and 6.4. The fields ‘Roof_Type’, ‘Wall_Type’ and ‘Floor_Type’ of the property table provided in Appendix D show the building materials used for constructing buildings in the affected properties.

6.4.5 Household income

Data on the approximate household income at each property, as described in Table 6.4 and its corresponding section, help to determine appropriate mean replacement cost per square metre for buildings. Data on the weekly mean household income of each property in the study area is mainly sourced from the NEXIS dataset and verified with the 2006 ABS census data. The field 'In_Group' of the property table provided in Appendix D shows the mean weekly household income of flood-prone properties. The mean household income does not vary widely in the suburbs in the study area (as shown in Table 5.3) and is lower than the mean household income of Australia (ABS 2006a).

6.4.6 Building replacement value

Building replacement value represents the average square metre construction cost of residential buildings. The building replacement value used in the study is derived from the Cordell building construction data developed by Reed Business Information Systems (IBNA 2007). The Cordell dataset collects detailed building cost information on a quarterly basis from 105 regions around Australia, comparing building costs from over 20,000 sources, and is regarded as the most reliable source of building construction data in Australia. The primary objective of the Cordell dataset is to assist insurance companies with consistent and reliable replacement cost estimation across the country (ASIC 2005). The Cordell dataset is accessible via the internet only for registered members and there is no provision for student research. Therefore, some secondary sources have been used for this study. The sources include several study reports published by Geoscience Australia such as "Earth Quake Risk in Newcastle & Lake Macquarie" and "Natural Hazard Risk in Perth, WA" (Dhu & Jones 2002; Jones, Middelmann & Corby 2005) and a website of a reputed insurance company (IBNA 2007).

The study uses per-square metre construction cost data obtained from Cordell to estimate building replacement value. The information on building occupancy classes, materials used for constructing buildings, and household income are used to choose appropriate per square metre construction costs for the buildings. Building floor space has been then multiplied with the per-square metre cost to replace the whole building. The percentage of property damage obtained from the stage-damage curves is then multiplied by the building replacement value to measure the economic loss in dollar of the buildings at a given flood water depth.

Tables 6.3 and 6.4 show the Cordell dataset of building replacement value - the per square metre construction cost for different types of residential buildings. Data in the Tables are in 2006 dollar values converted from their 2002 dollar values using the Inflation

Calculator provided in the Reserve Bank of Australia website. The estimate of building replacement value on the basis of the Cordell dataset may be unreliable for an individual property but it is reasonably accurate as an aggregated figure for a number of buildings over a larger area such as a suburb.

Occupancy Class	Description	Example	Mean Cost Per Square Metre
RES1	Single Family Dwelling	See Table 3.6	1118
RES2	Mobile House	Mobile House	786
RES3	Multi Family Dwelling	Apartment/Condominium	1398
RES4	Temporary Lodging	Hotel/Motel	1415
RES6	Nursing Home	Nursing Home	1327

Table 6.3: Replacement cost for residential buildings on per square metre basis (2006)

(Source: Dhu & Jones 2002)

Mean Construction Class	Concrete floor, brick veneer wall, pitched tile roof	Concrete floor, cavity brick walls, pitched tile roof	Concrete floor, timber walls, pitched metal roof
RES1 Economy	963	1129	919
RES1 Average	1444.5	1693.5	1378.5
RES1 Luxury	1926	2258	1838

Table 6.4: Replacement cost for single family residential buildings on per square basis (2006)

(Source: IBNA 2007)

The replacement value of buildings in the study area as estimated from the floor space and per square metre construction cost is shown in the 'Blg_Value' of the property table provided in Appendix D. the property table, 'Blg_Cost' represents the per-square metre construction cost chosen for the building. Figure 6.19 shows the spatial distribution of properties having a range of building replacement values in the study area.

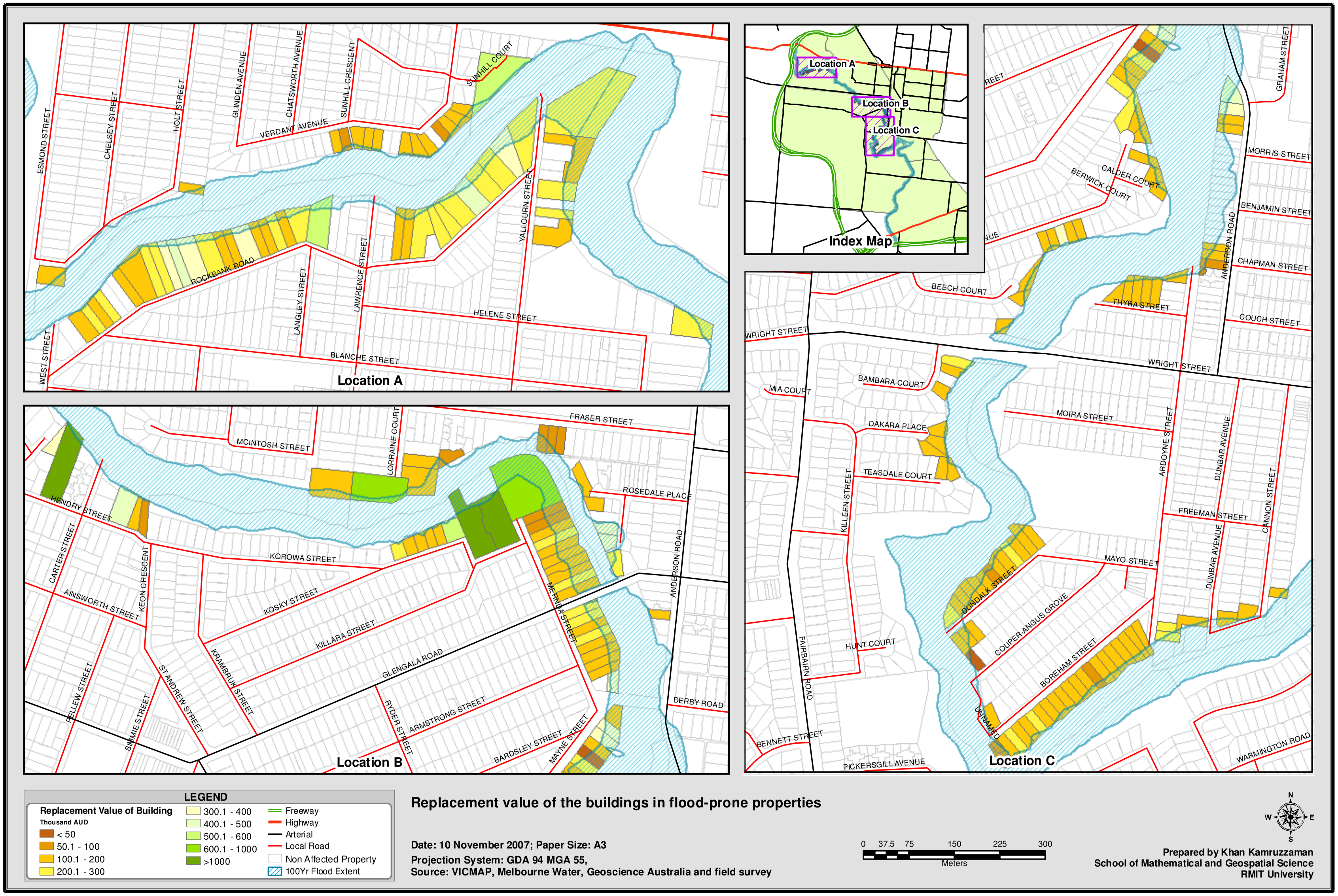

Figure 6-37: Replacement value of buildings on flood-prone properties

6.4.7 Age of buildings

Data on building age is needed to determine the economic value of a building based on a selected depreciation model. The age of a building is presumed from photos of the building taken during field surveys. The age of the building has been determined by the visual observation method. Photos were taken from outside each residential building within flood-prone properties. Then the age of the building has been predicted on the basis of the architectural style of the building exterior and materials used to build it. The predicted age of the buildings has further been reviewed by an experienced heritage architect to increase the precision of the prediction. The field 'Blg_Age' in the property table provided in Appendix D shows the age of the buildings. Figure 6.20 shows a spatial pattern of the age of buildings in flood-prone properties.

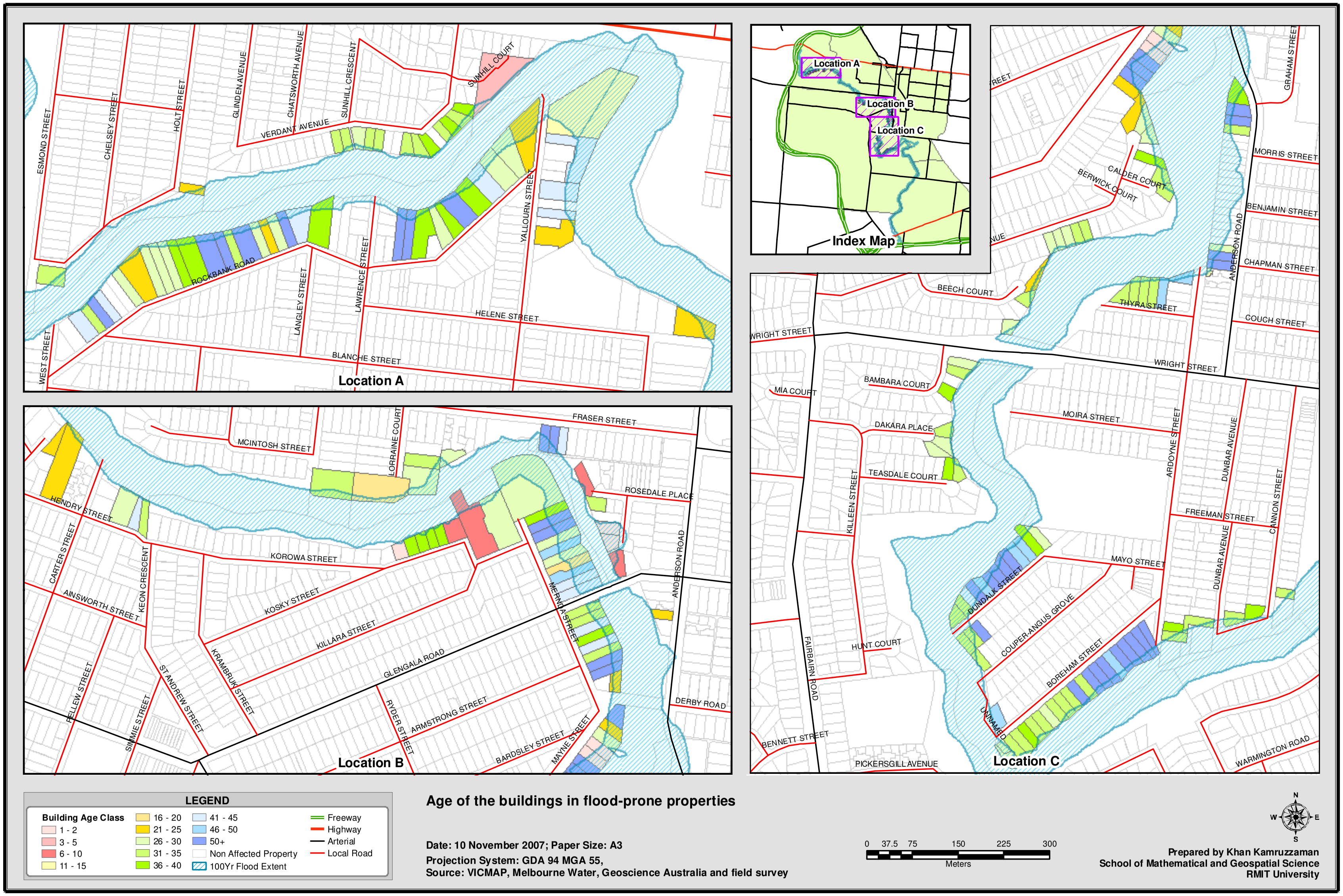

Figure 6-39: Age of buildings on flood-prone properties

6.4.8 Depreciation of building replacement value

Building replacement value represents the cost of constructing new buildings and does not represent the economic value of the buildings in the current market. Buildings like other assets depreciate over time due to use. Therefore, if a building is halfway through its life, its economic value would be half of its replacement value. To estimate the economic damage of a residential building it is necessary to depreciate its replacement value to obtain its economic value in the current market. For this purpose, two depreciation models are evaluated in this study: the HAZUS model (FEMA 2003) and the BTE formula (BTE 2001).

The HAZUS depreciation model was developed for single family residential buildings in terms of the general condition of construction (good, average and poor) and age of the buildings, based on extensive surveyed data conducted in the USA (FEMA 2003).

BTE (2001) provides a formula (see Appendix B) to determine the depreciated value of assets, based on some existing research (Thompson and Handmer 1996, Parker, Green and Thompson 1987). The formula assumes that the loss of the assets or buildings affected by floods should be calculated by their average remaining values which are taken as 50% of their replacement value. The assumption is more reasonable when a large number of buildings rather than an individual building or asset is considered.

The depreciation values derived from the HAZUS model and the BTE formula are compared in Figure 6.21 and Table 6.5.

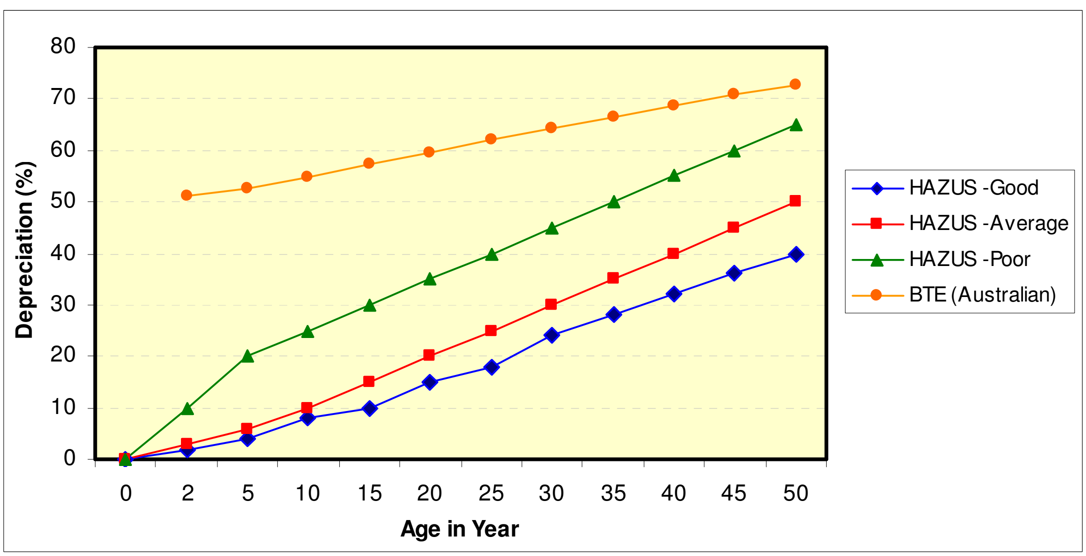

Figure 6-41: A comparison of depreciation models of buildings derived from HAZUS and BTE

(Source: BTE 2001 and FEMA 2003)

Age	% of depreciation in HAZUS			% of depreciation in BTE
	Good	**Average**	**Poor**	
0	0	0	0	
2	2	3	10	50.98
5	4	6	20	52.44933
10	8	10	25	54.88694
15	10	15	30	57.30131
20	15	20	35	59.68139
25	18	25	40	62.01674
30	24	30	45	64.29774
35	28	35	50	66.51573
40	32	40	55	68.66307
45	36	45	60	70.7333
50	40	50	65	72.7211

Table 6.5: Depreciation of buildings

(Source: BTE 2001 and FEMA 2003)

Note that the BTE depreciation curve starts from 50% and therefore it may generate an erroneous estimation. For example, it shows that the value of a building will be halved 2 years after its construction. On the other hand, the HAZUS depreciation model offers three depreciation curves to reflect the condition of the building construction (good, average and bad). The depreciation curves start from 0% and increase gradually with the age of the buildings. For example, the depreciation curves show that the value of a building will be about 2-10% of its replacement value after 2 years of its construction, depending on the type of construction. This depreciation model is a more accurate one for property level analysis.

The field ‘Blg_Ec_Val’ of the property table provided in Appendix D shows the economic value of flood-prone buildings in the study area, calculated with the HAZUS depreciation model. Figure 6.23 shows a spatial pattern of the economic value of flood-prone buildings in the study area.

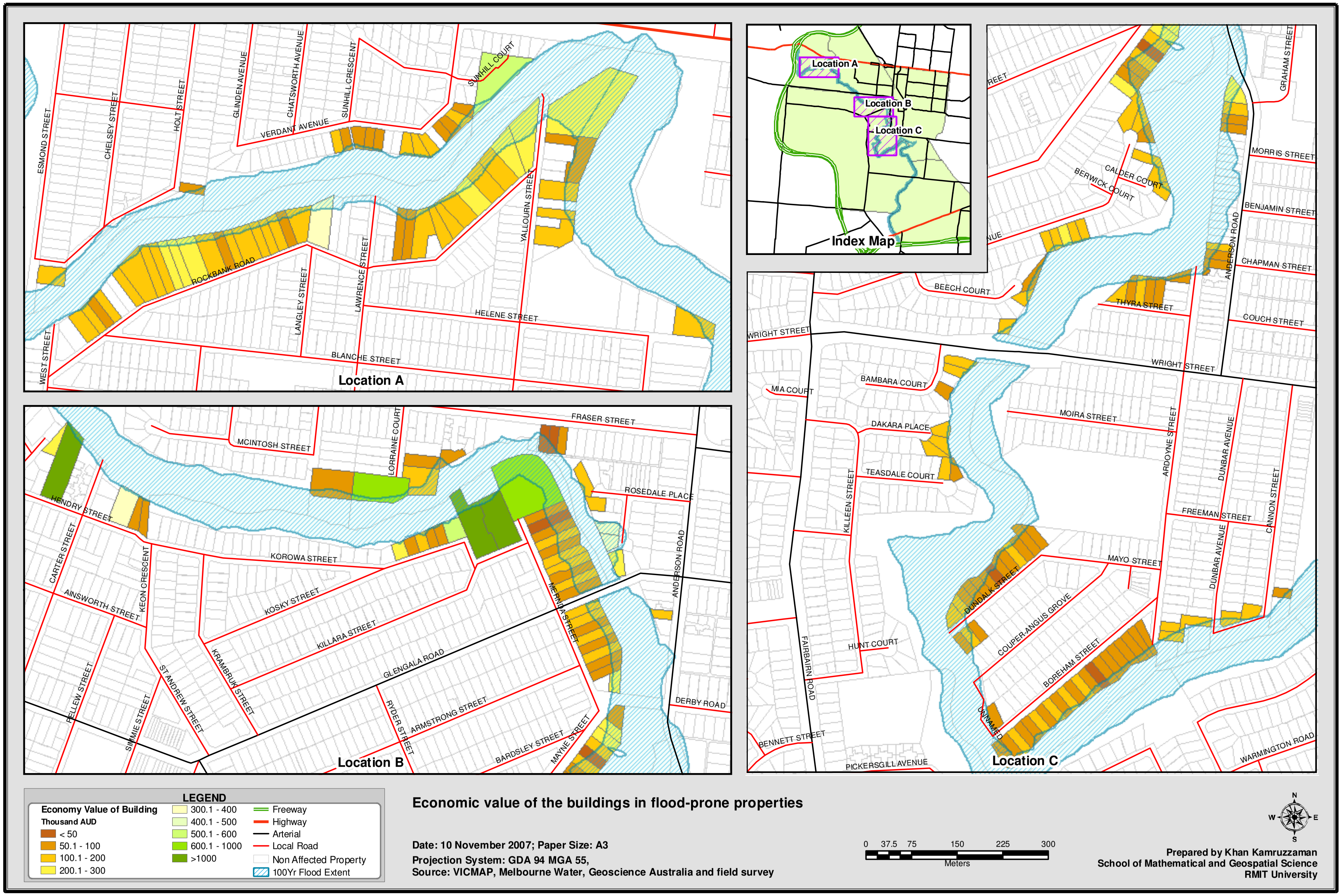

Figure 6-43: Economic value of buildings on flood-prone properties

6.4.9 Ground floor height

Data on ground floor height represents the height, in metres, above AHD (Australian Height Datum), of the ground floor of the buildings on a property. This data was obtained for the study area from Melbourne Water. Data on ground floor height and on the floor space was collected by Melbourne Water during a field survey in 1997 (MW 2007c). Ground floor height is used, together with the flood level surface, to determine the flood depth at each building relative to the ground floor. The details on how to measure flood depth at a building is discussed in Section 6.7.1.

6.4.10 Contents value

Data on the total content value of each property in the study area is derived from the mean household income in the NEXIS dataset. This study will use the contents value obtained from the NEXIS dataset. The field 'Cnt_Val' of the property table provided in Appendix D shows the contents value of buildings in the affected properties. Figure 6.23 shows a spatial pattern of the contents value of buildings in the flood-prone area.

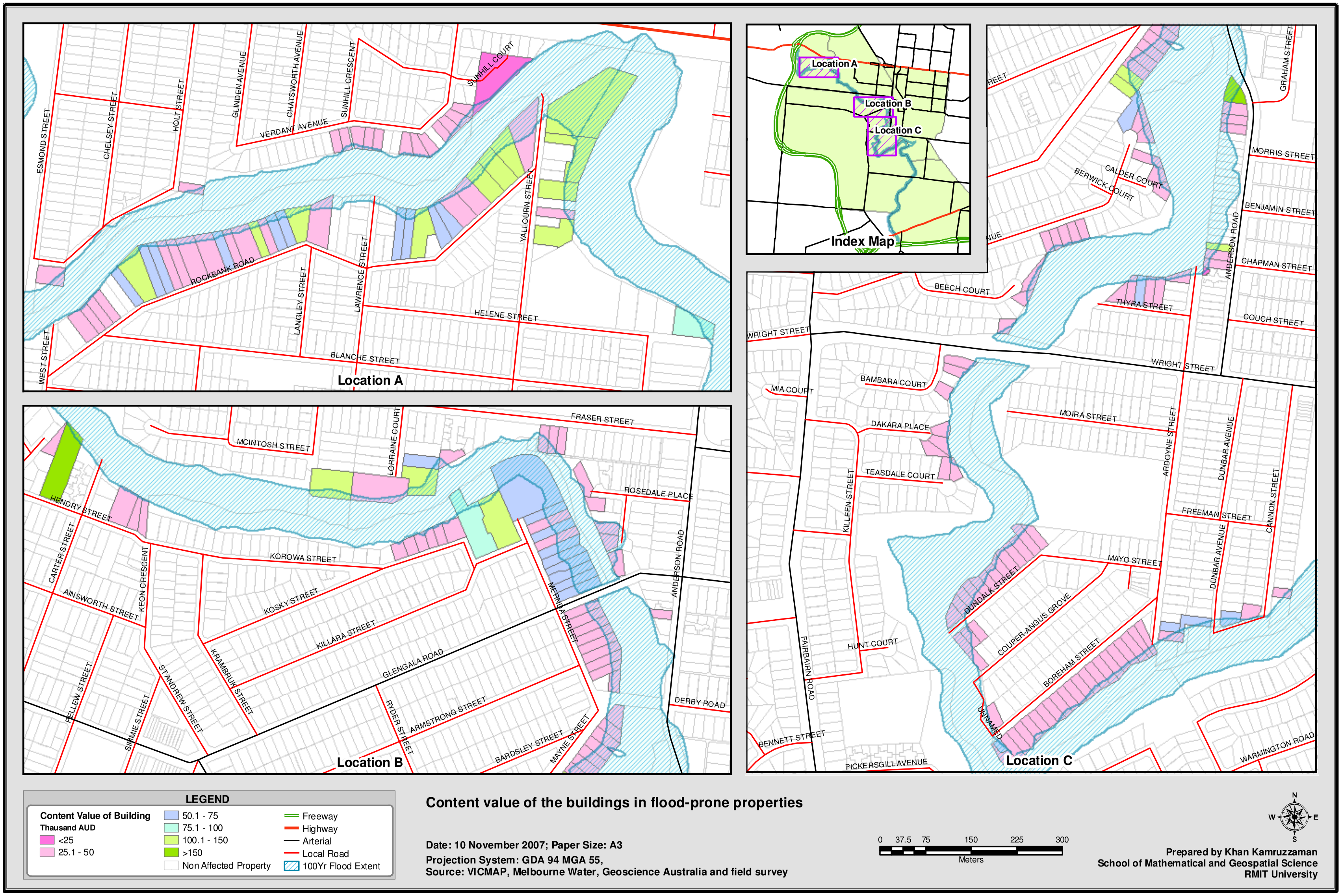

Figure 6-45: Contents value of buildings on flood-prone properties

6.5 ADOPTING STAGE-DAMAGE CURVES

Stage-damage curves are two dimensional graphs showing the relationship between the depth of flood water relative to ground floor height and expected damage of building structures or building contents. Two sets of stage-damage curves have been used for the study: HAZUS curves are used for estimating structural damage and NHRC curves are used for estimating contents damage. HAZUS curves have been developed from extensive data surveyed in the USA and the NHRC curves are adopted from FLAIR (UK) and based on surveyed data conducted in Australia (FEMA 2003; Smith and Handmer 2002). The default stage-damage curves for 1 and 2 storey single family residential buildings derived from HAZUS and stage-damage curves derived from NHRC are shown in Figure 6.25 and Table 6.6. Figure 6.24 shows that there is a good agreement between HAZUS and NHRC in structural damage curves for single family residential buildings. This study follows the HAZUS curves since the HAZUS model uses different curves for different classes of buildings.

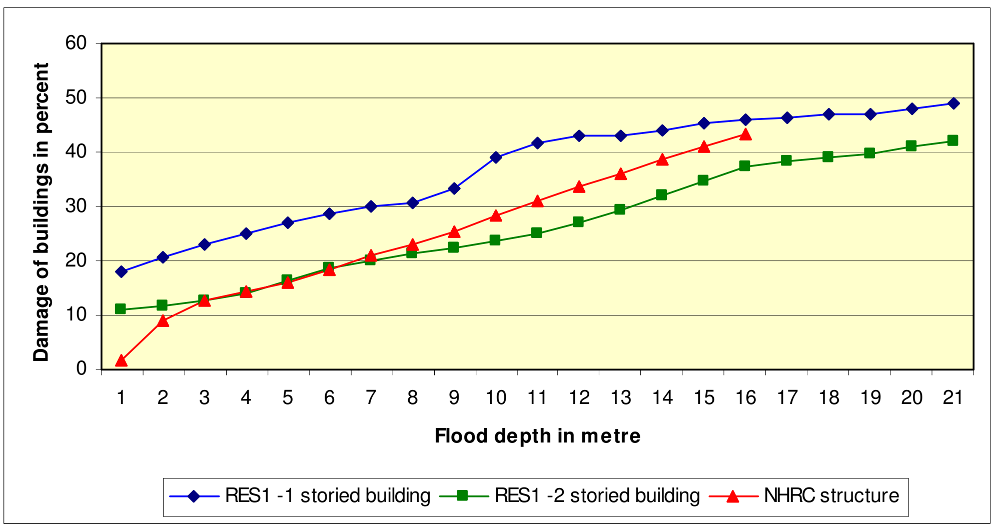

Figure 6-47: Stage-damage curves for structure

Source: FEMA (2003); Smith and Handmer (2002)

Flood depth (m)	RES1 -1 storied building (% of damage)	RES1 -2 storied building (% of damage)	NHRC (% of damage)
0	18	11	1.8
0.2	20.62	11.66	9
0.4	22.94	12.62	12.53
0.6	24.90	13.94	14.4
0.8	26.87	16.50	16.13
1	28.56	18.56	18.33
1.2	29.8740	19.87	21
1.4	30.59	21.19	23
1.6	33.24	22.50	25.4
1.8	39.15	23.81	28.2
2	41.68	25.12	31.06
2.2	43	26.87	33.66
2.4	43	29.50	36
2.6	44.06	32.12	38.6
2.8	45.19	34.75	41
3	45.84	37.37	43.2
3.2	46.50	38.50	
3.4	47	39.15	
3.6	47	39.81	
3.8	47.93	40.93	
4	48.99	41.99	

Table 6.6: Stage-damage table for structure

Source: FEMA (2003); Smith and Handmer (2002)

Due to the significant difference in contents damage between the HAZUS and the NHRC curves, as shown in Figure 6.25 and Table 6.6, the study follows NHRC curves for contents damage assessment as it is based on Australian flood data.

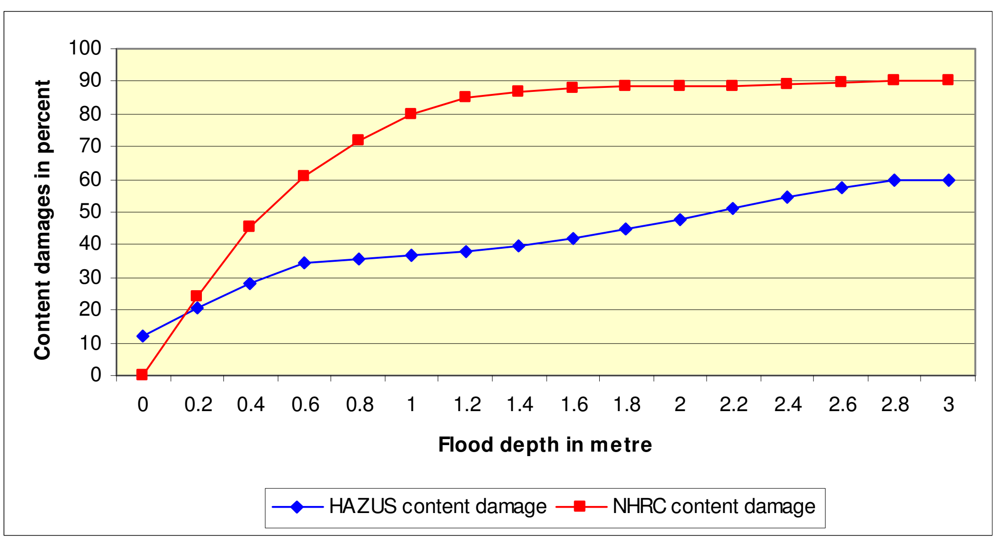

Figure 6-49: Stage-damage curves for contents

Source: FEMA (2003); Smith and Handmer (2002)

Flood depth (m)	HAZUS (% of damage)	NHRC (% of damage)
0	12.00	0.00
0.2	20.67	24.00
0.4	28.23	45.57
0.6	34.68	60.70
0.8	35.54	71.70
1	36.60	79.87
1.2	37.87	85.20
1.4	39.82	86.67
1.6	42.07	87.73
1.8	44.61	88.40
2	47.87	88.53
2.2	51.12	88.67
2.4	54.35	88.80
2.6	57.67	89.60
2.8	59.55	90.07
3	60.00	90.20

Table 6.7: Stage-damage table for contents

Source: FEMA (2003); Smith and Handmer (2002)

The field 'DmgCrv_Used' of the property table provided in Appendix D shows the stage-damage curves used for buildings in flood-prone properties.

6.6 MEASURING DAMAGE

The procedure for measuring damage in this study includes four steps: (1) calculate flood depth at buildings; (2) measure structural damage; (3) measure contents damage; and (4) summarise the damage.

6.6.1 Calculating Flood depth at buildings

Flood depth at buildings refers to flood depth relative to ground floor height at buildings in each property in the study area. In this study, flood depth is estimated for all flood-prone buildings and recorded in the building dataset. The information of flood depth at buildings is then transferred from the building dataset into the property dataset (see Figure 6.13). In the case of more than one building on a property, the average flood depth of buildings in a property is calculated and then transferred into the property dataset. In calculating flood depth at buildings, if the boundary of a 100 year flood extent does not intersect a building, it is not included in the flood depth calculation procedure. The value of the flood depth to these buildings is shown as 999999 (as a null value).

A GIS based raster analysis process is deployed to calculate flood depth at buildings using building footprint shapes from the building dataset, property area shapes from the property dataset, and surfaces of flood level and flood depth. The process involves measuring and calculating: (1) flood levels in metres above AHD (Australian Height Datum) at buildings from the flood level surface; (2) building ground floor heights in metres above AHD from the property dataset; (3) flood depths relative to ground floor height at each building is calculated and (4) average flood depth of buildings on a property is transferred into the property dataset as all processes of loss assessment are conducted on the property dataset.

A zero flood depth at a building or property indicates that the flood level is the same as ground floor height. But flood damage may start at zero, or even negative flood depth, in a building with a basement. Therefore, zero and negative values of flood depth are considered and used in measuring structural damage and contents damage analysis in this study.

The field 'Flood_Depth' of the property table provided in Appendix D shows the average flood depth at buildings in flood-prone properties. Figure 6.26 shows a spatial distribution of flood depth at buildings in the study area.

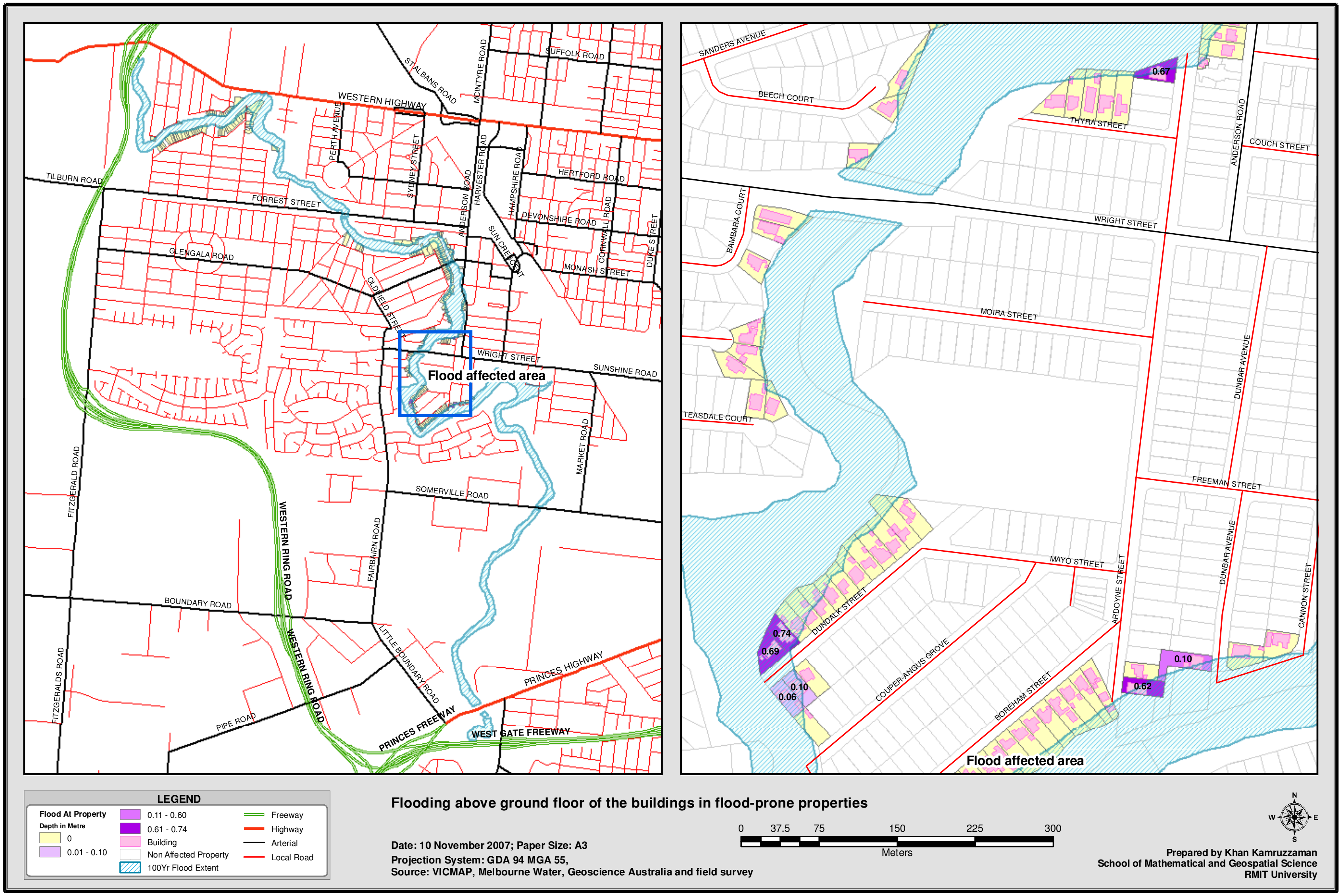

Figure 6-51: Flooding above ground floor of buildings on flood-prone properties

6.6.2 Measuring structural damage

Expected structural damage of buildings is measured by using two sets of information, flood depth at buildings and stage-damage curves of different building occupancy classes.

The percentage of structural damage estimated from the selected stage-damage curve is multiplied by the economic value of buildings identified through the building inventory. This gives the structural damage of buildings in dollars. As the economic value of buildings is in 2006 dollar value, the structural damage of buildings is also in 2006 dollar value.

The fields 'SDmg_Per' and 'SDmg_Doll' of the property table provided in Appendix D show the building structure damage of flood-prone residential properties in the study area, in percentage and dollars respectively. Figure 6.27 shows the spatial distribution of structural damage of buildings in the study area. Summarised structural damage of buildings and the number of properties suffering structural damage derived from the analysis are shown in Table 6.8.

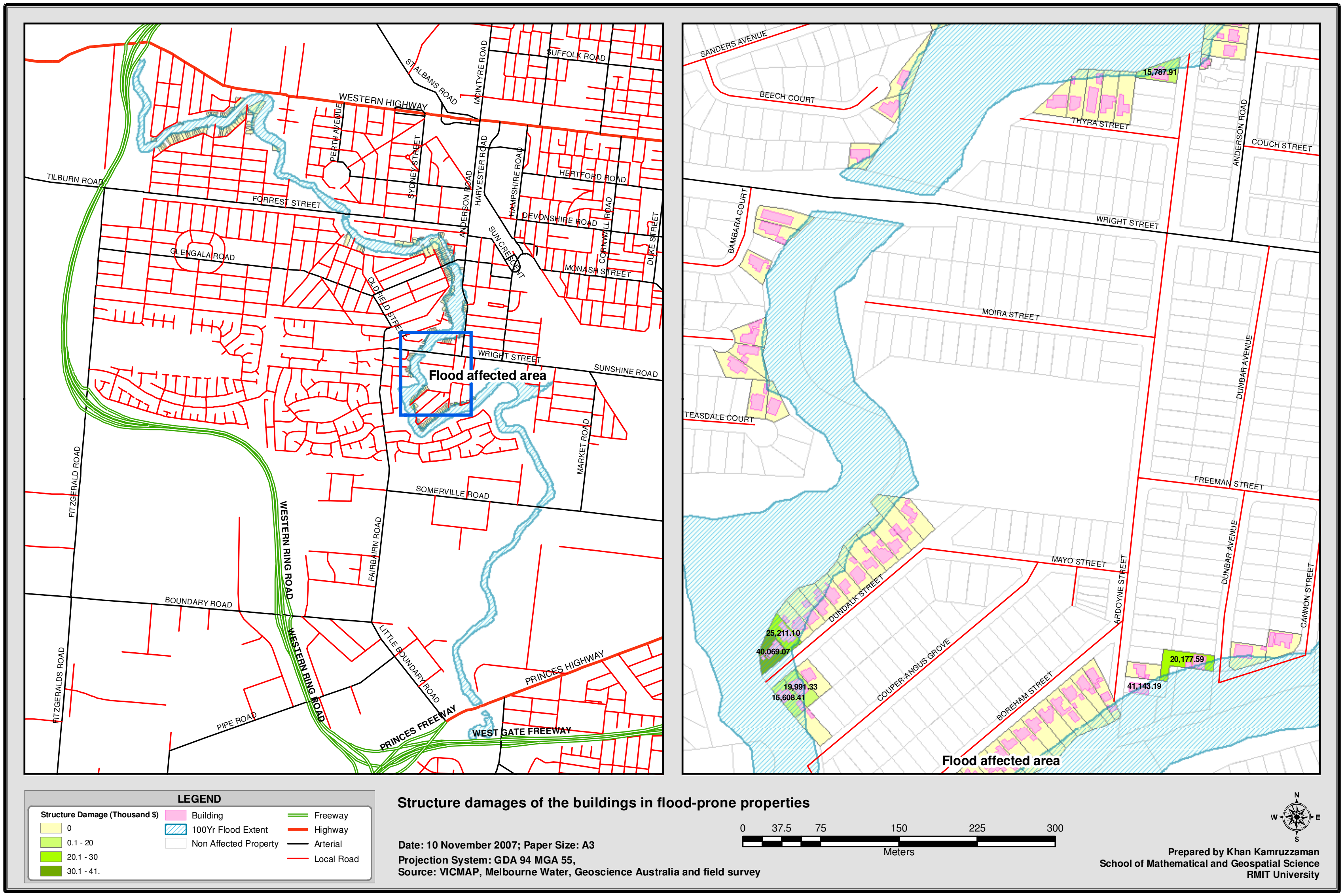

Figure 6-53: Structural damage of buildings on flood-prone properties

6.6.3 Measuring contents damage

The contents damage of properties is measured in the same manner as structural damage is measured, but using different datasets: stage-damage curves for contents have been used to get the contents damage in a percentage which is multiplied by contents value instead of the economic value of buildings.

The fields 'CDmg_Per' and 'CDmg_Doll' of the property table provided in Appendix 3 show the building contents damage of flood-prone residential properties in the study area, in percent and dollar respectively. Figure 6.28 shows a spatial distribution of building contents damage of flood-prone residential properties in the study area. Summarised structural damage of buildings and the number of properties suffering structural damage derived from the analysis are shown in Table 6.8.

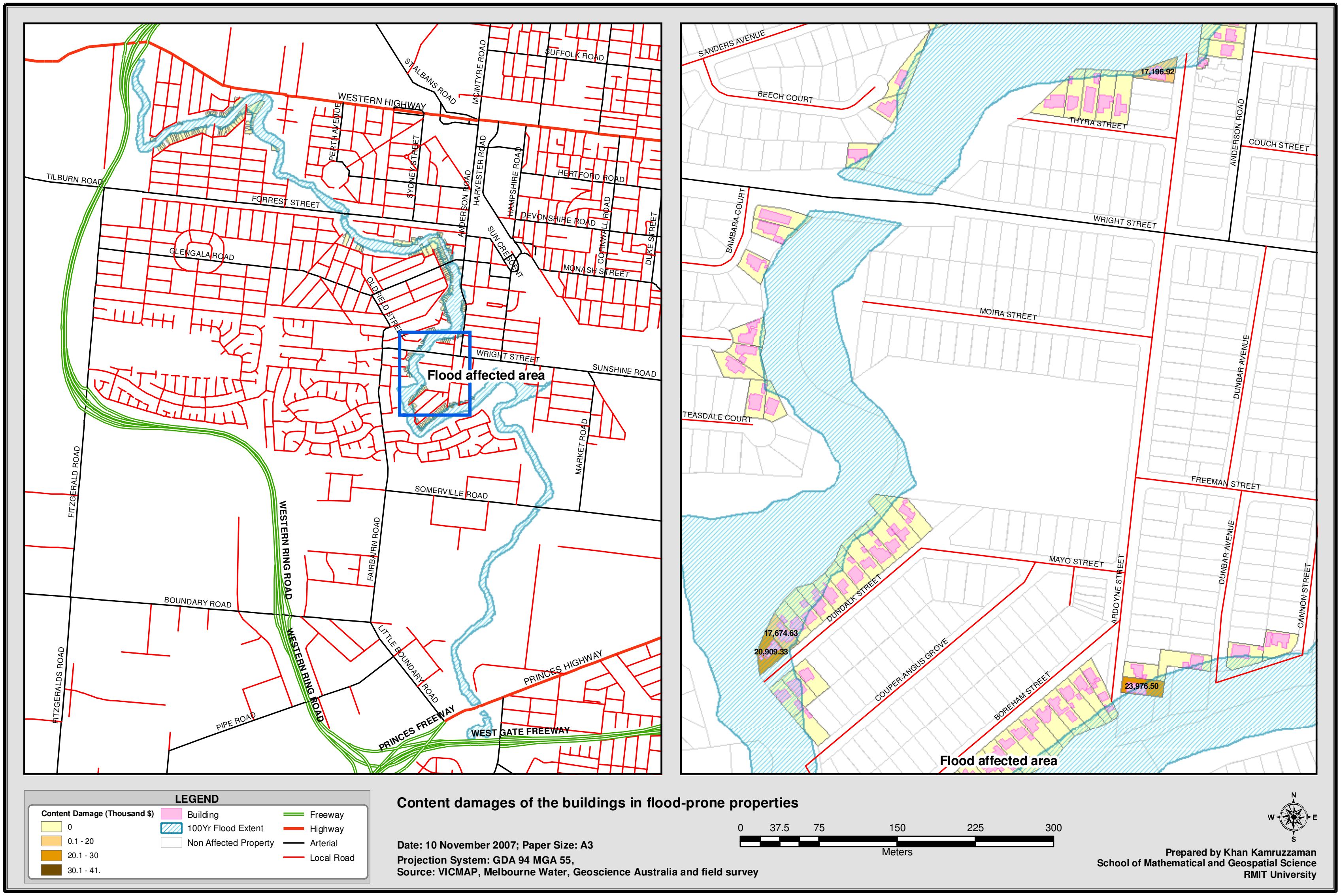

Figure 6-55: Contents damage of buildings on flood-prone properties

6.6.4 Summarising damages

Expected total damage to a flood-prone residential property is measured by a simple process of adding up its structural and contents damages. The field 'TDmg_Doll' of the property table provided in Appendix D shows the combined building structure and contents damages of individual flood-prone residential property in the study area. Damages induced from individual properties of each category are summarised and given in Table 6.8.

Damage type	Dollar 000's	Number of property affected
Structuraltural damages	178.98	7
Contents damages	79.75	7
Total combined damages	258.73	7

Table 6.8: Summarised economic damages of residential buildings in the study area

6.7 VALIDATING RESULTS

Results generated from the methodology implemented in this study are validated from three different aspects: validation of flood level, validation of floor space and validation of stage-damage curves.

6.7.1 Validation of flood level

Accurate flood level is essential in determining reliable flood depth at buildings and ultimately the total damage at a flood-prone residential property.

To validate the flood level derived in this study, average flood levels (in metres above AHD) at properties derived from this study are compared with the flood levels measured by Melbourne Water, as shown in Figure 6.29. The figure shows a good agreement between the two datasets. RMSE calculated from the datasets is 0.072544, which represents a pretty good agreement as well at one metre pixel resolution of flood level DEM (Discussion on RMSE can be found in Appendix C). The good agreements between the two datasets validated the procedure of mapping flood level surfaces to a certain degree.

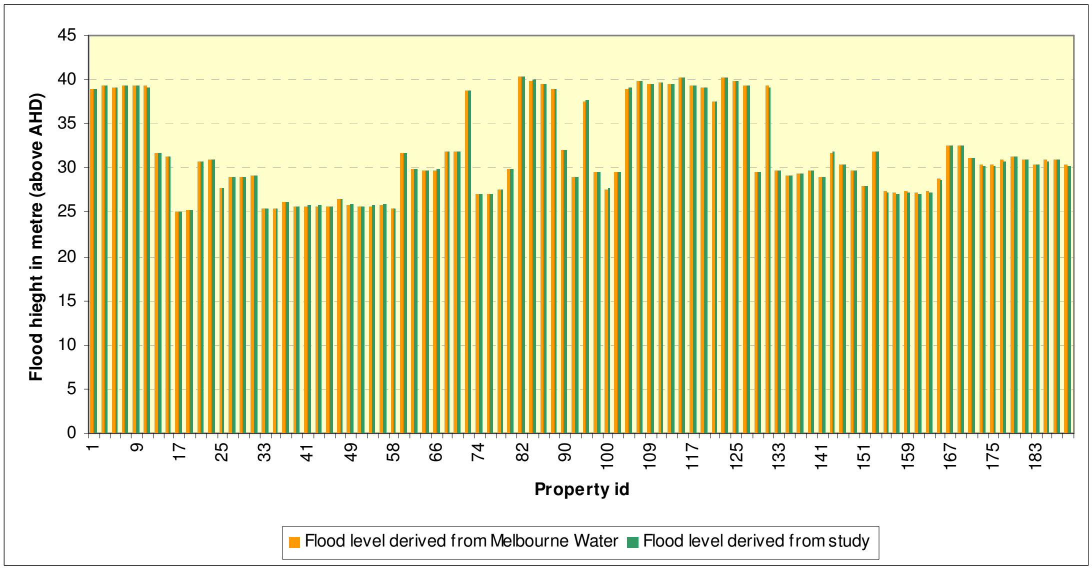

Figure 6-57: Comparison between flood levels measured by Melbourne Water and average flood levels at properties derived in this study.

6.7.2 Validation of floor space

The floor space of the building derived from the method used by this study has also been compared favourably with that obtained from NEXIS dataset, as shown in Figure 6.30. This is also indicated by the small standardised RMSE (= 1.027) calculated using the 169 records of floor area that fall within one standard deviation limits from the sample mean. Of the 191 records, only 22 records fall outside these one standard deviation limits.

In addition, the total floor space of identified buildings calculated in the study is 48,148 square metres, comparable to 42, 994 square metres according to the NEXIS dataset. The 11% difference between the two figures may be explained by the fact that the NEXIS dataset is based on the ABS surveyed data conducted approximately 9 years ago (GA 2006) and therefore it does not include new buildings constructed in recent years.

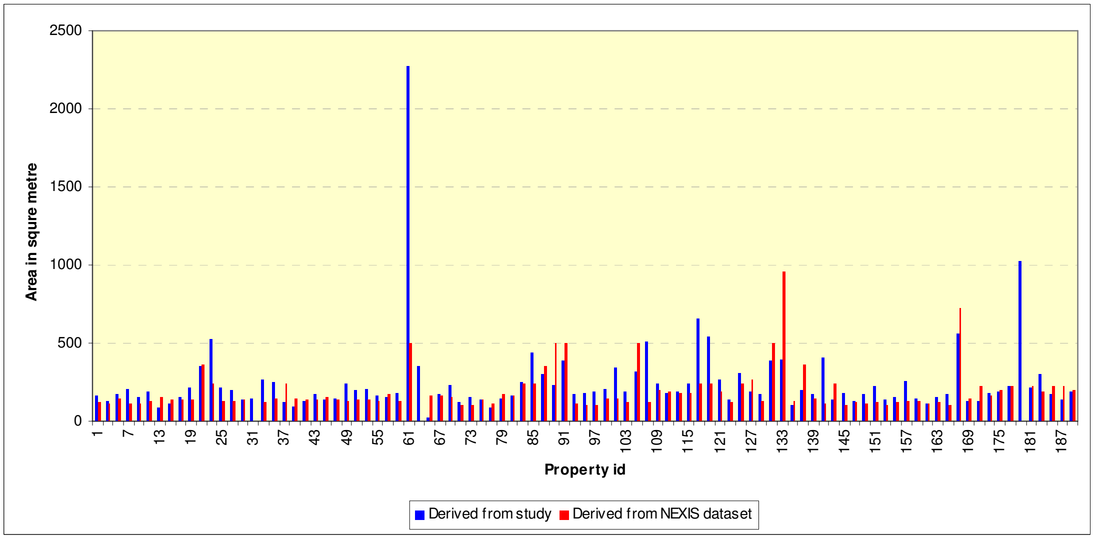

Figure 6-59: Comparison between NEXIS dataset and study derived data in respect of floor space at properties

6.7.3 Validation of stage-damage curves

Theoretically, the stage-damage curves can only be validated with actual losses measured through extensive field surveys immediately after actual floods occur in the local area. In this study, it is justifiable to adopt HAZUS curves for estimating structural damage and NHRC curves for estimating contents damage. This is because there is a good agreement between HAZUS and NHRC in structural damage curves for single family residential buildings, as shown in Figure 6.24 and Table 6.6.

6.8 CONCLUSION

This chapter presents in detail the procedures involved in, as well as the results derived from, a GIS based approach to economic assessment of the expected flood damage of residential properties in the study area, including on a segment of the Kororoit Creek and its adjacent area, given a 100 year flood event.

One of the important and critical parts of implementing the method in the study area is the collection of relevant datasets, especially the building inventory data. In Australia, it is hard to obtain property level building inventory data with satisfactory levels of accuracy unless extensive and detailed field surveys are conducted immediately after flood events. In this study, reasonable quality building inventory information derived from the NEXIS dataset, fine resolution aerial photos and a quick field survey has enabled the generation of a reasonably accurate estimation of flood damages at the property level. Better results are expected from the developed method with more reliable and precise building inventory data.

The procedures developed for mapping flood surfaces also generate reasonably accurate flood levels of properties as compared to the flood levels measured by Melbourne Water.

The next chapter evaluates the methodology deployed in the study, with a view on how the different components of the methodology could be improved and how the methodology could be enhanced by incorporating new procedures in order to achieve a better economic assessment of the flood damage of residential properties.

CHAPTER 7:

CONCLUSION

7.1 INTRODUCTION

Chapter 6 discussed in detail the procedures for economic assessment of residential flood damage, the required data and their sources, implementation of the procedures and validation of the results derived from the procedures. This chapter summarises research findings, illustrates limitations of the research, identifies some scope for further studies and draws some conclusions.

7.2 SUMMARY OF RESEARCH FINDINGS

This study is guided by the research objective of developing a GIS based procedure for the economic assessment of residential flood damage at property level. To achieve the research objective, a conceptual and theoretical understanding of floods and flood damage assessment are the prerequisite requirement. In this context, Chapter 2 defines floods and distinguishes between their types, their different components and their physical characteristics. On the other hand, Chapter 3 discusses various aspects of flood damage and approaches for their assessment including: types of flood damage, components of flood damage, types of assessment, stage-damage curves, average annual damage, and theoretical approaches to flood assessment.

This study reviews three renowned flood damage assessment models including the HAZUS model, the RAM model and the NHRC curves. This review provides: (a) a basis for conducting the study; (b) theoretical and conceptual concepts of flood and flood damage assessment; (c) concepts for structuring the framework of the study procedure; and (d) perceptions on how GIS can be used in different analytical steps of the study. Section 3.8 discusses more on the review of flood damage assessment models.

The research objective was addressed through a set of research questions (refer to Section 1.2). The research questions are answered in different sections in Chapter 4 and 6. The following sections summarise the findings of the research to review whether the research questions are answered properly. The sections include: (**1**) flood modelling procedures; (**2**) collecting and organising building inventory data; (**3**) adopting stage-damage curves; and (**4**) measuring damage.

7.2.1 Flood modelling procedure

A flood model with a fine resolution is required to find the average flood depth at buildings relative to their ground floor height. It is from this basis that damage to buildings is estimated. Flood modelling, the first analytical part of the study procedure, interpolates a flood level surface from a set of flood data including flood extent, flood level cut line, stream network and ground elevation contour. The flood modelling procedure, as shown in

Figure 7.1, comprises of a series of GIS based analytical procedures. GIS with its extensive capabilities in spatial analysis such as intersection, clipping, buffering, generalising, densifying vertices, attribute calculation, vector to raster conversion and interpolation enables a surface layer to be generated over the study area (raster layer) of the flood level. A DEM (Digital Elevation Model) of ground surface elevation with a fine resolution is then used to generate a flood depth surface. The DEM is generated by performing a GIS based spatial interpolation process using elevation contour lines. Figure 4.1, 4.2 and 4.3 and their corresponding sections illustrate, in detail, each of the analytical procedures.

This study focuses more on damage assessment procedures rather than flood modelling. The flood modelling procedure employed in the study generates a basic flood model which can be further improved by performing a set of hydrological analysis as stated in Section 7.3.1.

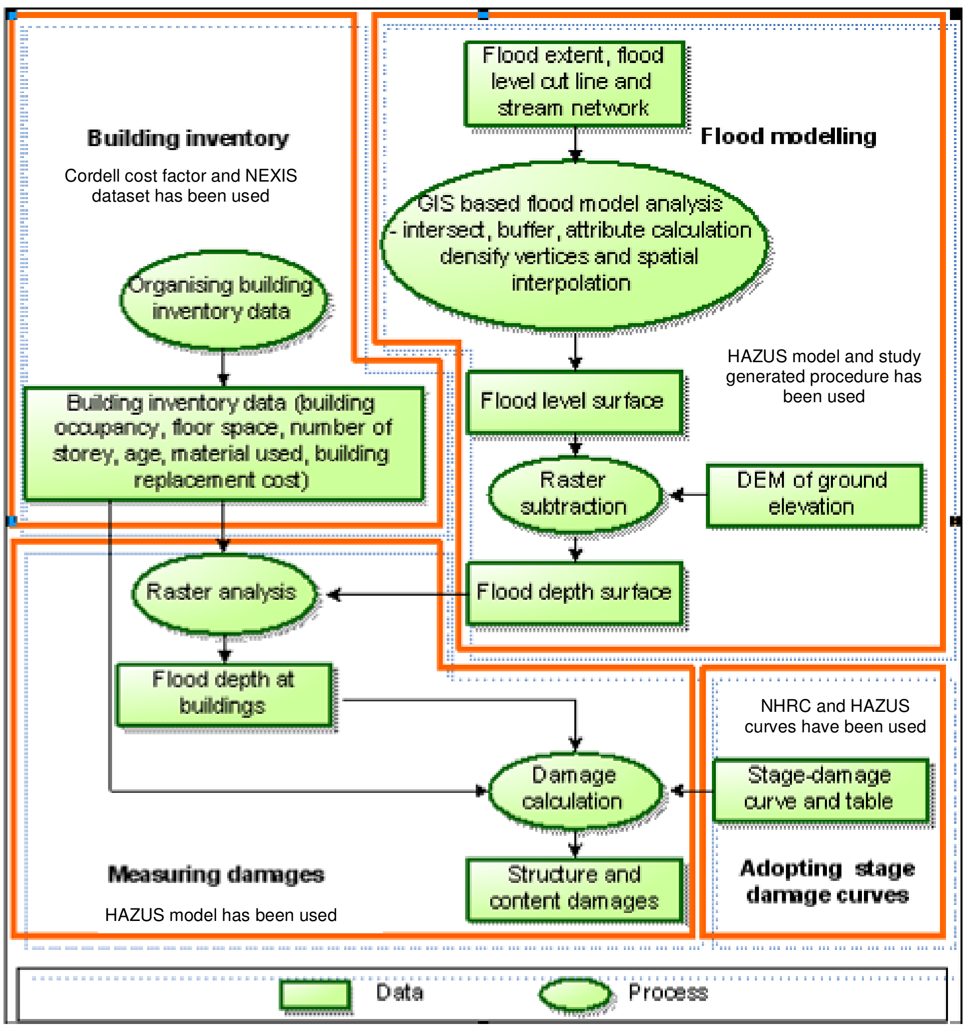

Figure 7-1: Summary process of a GIS based residential flood damage assessment

7.2.2 Collecting and organising building inventory data

According to Figure 7.1 a set of building inventory data is required to estimate residential flood damage which includes building occupancy, floor space, age of the building, number of storeys, building materials used, ground floor height, economic value of the building structure and contents value. The study deployed procedures to estimate the flood damage at a property level therefore; it requires building inventory data at the property level. In Australia, readily available building inventory data at a property level is rarely available. In addition, the quality of the data might not be satisfactory at the property level. Keeping these aspects in mind this study has researched sources of appropriate building inventory data for use in examining its deployed procedures. The sources of readily available building inventory data for research purposes are NEXIS, Melbourne Water, aerial photos, and a quick field survey. Detailed discussion of the building inventory data and their sources is given in Section 6.2.2.

Apart from the building inventory data as mentioned above, several models/assumptions are used in the flood damage assessment procedures of this study such as 'metre square building replacement value' - obtained from the Cordell database and 'depreciation model of building replacement value' – obtained from the HAZUS model. The models/ assumptions are used to estimate the current market value of buildings. Both of the models/assumptions are based on extensive surveys and the most reliable among the available models. However, the estimated current market value of buildings should be verified with an actual dataset. The Valuer-General Victoria (VGV) is a government agency who performs valuations on properties across Victoria. They developed a database of price and details of every property (including building and land) sold in Victoria. The VGV database is not accessible for student research purposes so therefore it is not possible to verify the estimated market value of the buildings in the study. However, the VGV dataset could be incorporated in the study procedure for further studies.

The building inventory data are organised and stored in attributes of two polygon shape files (ArcGIS features). These two datasets (polygon shape files) are the building dataset and the property dataset, where the building dataset represents the footprints of the buildings and the property dataset represents the boundaries of the properties. Damage estimation procedures are conducted on the basis of the property dataset. A number of the building inventory data are organised, calculated and stored in the building dataset; however, these are later transferred into the property dataset. Figure 6.13 and its corresponding section describe in detail the property and building dataset.

7.2.3 Adopting stage-damage curves

As the study follows the conceptual framework of the Synthetic Approach (Section 3.7.2), a set of stage-damage curves is a mandatory component in the flood damage assessment procedures. The study is only concerned with the structural and contents damage of residential buildings, thus it needs stage-damage curves. The HAZUS curves are used for the structural damage and the NHRC curves are used for contents damage in the study. These curves are used in the damages calculation procedure (see figure 7.1).

Stage-damage curves are one of the important components in flood damage assessment as they directly determine the damages estimate and therefore, they should reflect the building characteristics as closely as possible. HAZUS includes the most rigorous curves of all, as they are classified widely on the basis of building characteristics. On the other hand, NHRC curves were originally adopted from UK curves and then modified on the basis of Australian flood data. NHRC is one of the most commonly used flood-damage curves in Australia. However, they do not reflect the detailed building characteristics in the way that HAZUS curves do. Sections 4.4 and 6.6 elaborate on how the stage-damage curves were adopted for the study.

7.2.4 Measuring damage

According to Figure 7.1, the first part of the measuring damage procedure includes a GIS based raster analysis which calculates the average flood depth of the building above the ground floor. The second part of the analysis uses the flood depth information and stage-damage table to estimate the damage to the buildings as a percentage. The building inventory dataset is then used to estimate damages in dollar terms of the buildings affected by the flood. The resultant damages are highly influenced by input data. Section 6.7 elaborates on the procedures for measuring damage, including their implementation using a case study approach.

The procedures discussed in the sections 7.2.1 to 7.2.4 were tested using a case study approach where a segment of Kororoit Creek was taken as a study area and a number of data sources were used including Melbourne Water, NEXIS and VICMAP data. The data required at property level for implementing the procedures includes, basic building inventory data, flood data and stage-damage curves. The accuracy of the damages estimates derived from the study using the above mentioned data sources are more applicable at a suburb level than at a property level. However, the damages estimates derived from the study procedure are at a finer resolution than any other commonly used models in Australia.

7.3 LIMITATIONS OF THE RESEARCH

7.3.1 Flood model

This study develops an economic damages assessment procedure for residential flood damage where a flood model is required to calculate the flood depth at flood-prone buildings. This study includes a procedure to map (or model) the flood levels or flood depth using a set of data obtained from Melbourne Water. The flood model procedures deployed in this study employ ArcGIS software to generate a basic flood model. Hydrological analysis can be used to improve the flood model generated from study procedures. HEC-RAS, developed by the US Army Corps of Engineers is one of the more specialised computer softwares for performing a hydrological analysis and generating a sophisticated flood model (US Army Crops of Engineers 2005).

The generated flood model from this study deployed procedures which can be improved by including the following analysis and features: (**a**) hydraulic analysis; (**b**) regulation of river flow; (**c**) embankments, and (**d**) pools.

(a) Hydraulic analysis consists of a series of steps to refine the flood extent and flood level cut lines which then generate highly accurate flood models. The use of the Manning equation is one example of hydraulic analysis which considers the slope of the flood plain and velocity of the flood water to refine the flood plain extent and the alignment of flood level cut lines (FEMA 2003a). Though hydraulic analysis is not included in this study it can be included in flood modelling procedures in any further study.

(b) Regulation of river flow such as a diversion or storage influences the flood scenario. The flow of a river may be diverted in a different direction, thus the water may not flow in its original direction. For this reason, the flood may not occur in the downstream areas where the river flow was originally directed (Committee on Floodplain Mapping Technologies 2007). The study does not include any regulation of the river flow.

(c) In general, a DEM is not reliable for identifying a continuous embankment with relatively little width (Burkham 1978). Sometimes embankments with little width are represented in a DEM as incorrect or discontinuous alignment forms. This study does not include the procedure to include continuous embankments. HEC-RAS software can be used to incorporate embankments such as vector lines (US Army Crops of Engineers 2005).

(d) Areas of ponds or pools that do not convey floodwater should be removed from the flood modelling. This feature can change the inundation scenario of an area. This study includes pools and ponds in the flood modelling procedure.

7.3.2 Excluding estimation of actual damage

In flood damage assessment procedures, it is important to decide whether to estimate actual damage or potential damage. Actual damage is that which is estimated after a real flood event. Account is taken of the unique features of the event, the warning system, the community's experience with the flood hazards and their preparedness (Black & Evans 1999). In contrast, potential damage is that which is likely to occur in a real flood event as well as in a hypothetical flood event. Potential damage does not take account of unique features of an event or of the measurement that reduces flood impacts (Smith & Handmer 2002)

The Rapid Appraisal Method (RAM) has developed a set of ratios between actual and potential damage which are shown in table 3.4. This study does not include the procedure for estimating the actual damage. This study procedure can only generate potential damage. However, actual damage can be calculated using the ratios set out in the table 3.4. (See Section 3.8.2 for more clarification on actual and potential damage).

7.3.3 Excluding AAD calculation

Average Annual Damage (AAD) is the average damage in dollars per year in a particular area (Lo 1992). An area may have no flood damage for many years, may have minor damage (caused by small and relatively frequent floods) in some years, and may have major damage (caused by large and rare floods) in very few years. It is essential to include all floods in a damage estimation procedure to know the entire flood impact on that area in a long term.

Calculation of AAD evaluates the investments for different floodplain management measures that mitigate damage. At least 3 flood events are needed to calculate an AAD. This study only obtained data for one event – 100 year flood for Kororoit Creek and thus it does not calculate the AAD. However, damages estimates derived from the study can be used for calculating an AAD in any further study when other flood event datasets are available. Section 3.6 describes the procedure of AAD calculation.

7.3.4 Excluding depreciation of contents value

The study does not include a depreciation process of contents value like building structure because it did not find any contents depreciation model compatible for the study. It uses the contents value from NEXIS which is based on average household income. However, depreciation process for contents value can be added in the study procedure if a suitable model is available.

7.3.5 Adjustment of estimated damages with surveyed data

The damage estimates derived from Synthetic Approach may be compared with a surveyed damage data if the surveyed data is from an event of the same magnitude as the one considered by the Synthetic Approach. This study deals with a hypothetical event (the 100-year event) for damage estimation, and there is no surveyed damage data from an actually occurred 100-year event available to enable such a comparison. However, damage estimates from an actual flood in a similar kind of residential area can be used to refine the stage-damage curves and overall study methodology deployed in this study.

7.4 SCOPE FOR FURTHER RESEARCH

This research study recognises a number of areas for further research. These include: (**1**) developing a GIS based interactive software; (**2**) developing a consistent procedure for multi-hazard damage assessment; (**3**) developing a set of locally based stage-damage curves; (**4**) developing a consistent and rigorous building inventory dataset.

7.4.1 Developing a GIS based interactive software

A GIS based interactive software can be made for estimating flood damage. The conceptual algorithms of the procedures deployed in this study could be translated into computer programming code to develop the damage assessment software. The assessment steps of the proposed software can be organised according to the analytical procedures of the study such as flood modelling, organising a building inventory dataset, adopting stage-damage curves, and measuring damage. Each of the analytical steps may have default options that can be run on the default datasets embedded within the software to get a basic flood damage result. However, it might have additional options to modify default datasets or incorporate external datasets to get better results. Each of the analytical steps could be developed in a manner so that it would be run independently without running the previous analytical steps. For example, the process of organising the building inventory dataset could be performed without running the flood modelling processes.

7.4.2 Developing a consistent procedure for multi-hazard damage assessment

This study only includes the depth in flood modelling procedures. Other components of the flood such as velocity, duration and load can be included in flood modelling to preform a comprehensive analysis of flood damage assessment. This study only includes residential buildings; further research is required to include buildings other than residential, as well as all other direct, indirect, tangible and intangible damage. More research is needed to develop a procedure which covers modelling of all other natural hazards and damage assessment procedures induced from them. The two important aspects: consistency and fine resolution of accuracy should be considered in developing a multi-hazard damage assessment procedure.

7.4.3 Developing a set of locally based stage-damage curves

Stage-damage curves are one of the important components which influence the damage output directly. Therefore, the use of appropriate stage-damage curves leads to high quality damages results. The study uses the HAZUS curves and the NHRC curves. The HAZUS curves are more appropriate for USA and the NHRC curves are more appropriate for assessment of coarse resolution. In this context, further studies could be conducted to develop a set of localised and robust stage-damage curves on the basis of extensive survey data which reflects detailed building characteristics, physical and geo-morphological characteristics of catchments and settlement patterns. It is also important to make it accessible to all levels of people involved in damage assessment as well as those involved in the research.

7.4.4 Developing a consistent and rigorous building inventory dataset

Consistent methodology can not produce consistent damage results unless consistent data is provided. This study uses the NEXIS dataset which is a nation wide consistent building inventory dataset in Australia. However, the accuracy of the NEXIS dataset may not be reasonable at property level or when the study is aiming for fine resolution. From this context, further studies or initiatives are required for updating the NEXIS dataset or for developing a new nation wide consistent and rigorous dataset which can satisfy all levels of damage assessment: from fine level to coarse level resolution. Data from various sources such as the Valuer General, city councils, ABS and other government and private organisations could be used for updating or building the dataset. Further studies are also needed to reflect and incorporate in the proposed dataset the interests of various people at all levels related to natural hazards and property insurance.

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APPENDIX A: NEXIS DATABASE

National Building Exposure Database (NBED), recently named as National Exposure Information System (NEXIS) is developed by Geoscience Australia. NEXIS database contains a set of building inventory information for all properties around Australia to feed disaster loss estimation procedures. The primary purpose of NEXIS is developing a nation wide consistent database for buildings exposed to natural hazards which will ultimately assist to conduct a detailed risk or loss assessment process. The creation of NEXIS is based on a set of datasets such as ABS Cencus, ABS Meshblocks, ABS Housing Survey, Geocoded National Address File, StreetPro (from MapInfo) and Cadastre (from PSMA). It also incorporates Hazus models and Reed-Cordell building cost factors (IBNA 2007). The database is developed in ArcGIS (Nadimpalli 2007).

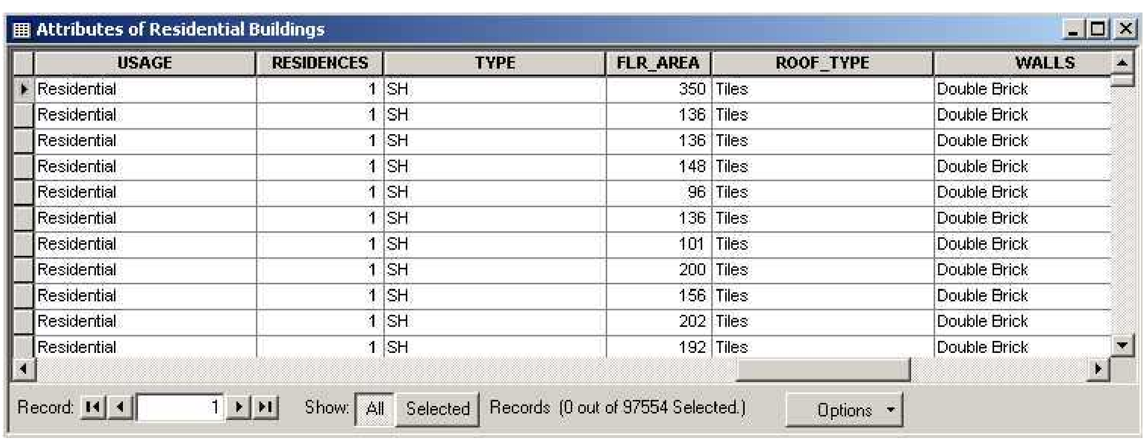
NEXIS includes the value for each structure and its contents. The replacement value of the structures is derived using floor space and the age of the buildings. On the other hand, the contents value is derived using floor space and household income. Currently, a nation-wide database for commercial buildings is being developed. The NEXIS database for residential buildings includes the features shown in Table A.1.

Variables	Datasets	Derived Information
Latitude Longitude	GNAF	Geo-coded Addresses
Address Block Size Floor Area	Cadastre	Floor Area (sq. m) was derived based on the location and size of the block.
Usage	ABS Meshblocks	Residential, agricultural, commercial, industrial etc.
Building Type	Cadastre, GNAF	Separate house, semidetached house and Apartment
Roof Type	ABS Housing survey	Tiled, metal, fibro
Wall Type	ABS Housing survey	Double brick, brick veneer, fibro, timber, concrete frame
Age	Building approvals	Period of construction
Number of Storeys	GNAF, Cadastre	Based on number of residences and size of the block
Population	ABS Census	Census district average population based on building type.
Household Income	ABS Census	Census district average
Building Value	Cost Factors	Replacement value
Contents Value	Insurance estimates	Based on household income and building value

Table A. 1: Residential building features included in NEXIS database and their source

Source: Nadimpalli et al. (2007)

There are also suggestions that more socio-economic information will be incorporated as new datasets or sources of information become available (COAG 2002). A screen shot of NEXIS database is given in figure A.1.


Attributes of Residential Buildings

USAGE	RESIDENCES	TYPE	FLR_AREA	ROOF_TYPE	WALLS
Residential	1	SH	350	Tiles	Double Brick
Residential	1	SH	136	Tiles	Double Brick
Residential	1	SH	136	Tiles	Double Brick
Residential	1	SH	148	Tiles	Double Brick
Residential	1	SH	96	Tiles	Double Brick
Residential	1	SH	136	Tiles	Double Brick
Residential	1	SH	101	Tiles	Double Brick
Residential	1	SH	200	Tiles	Double Brick
Residential	1	SH	156	Tiles	Double Brick
Residential	1	SH	202	Tiles	Double Brick
Residential	1	SH	192	Tiles	Double Brick

Record: 1 Show: All Selected Records (0 out of 97554 Selected.) Options

Figure A.1: Example of the NEXIS database
(Source: GA 2006)

APPENDIX B: DEPRECIATED VALUE OF AN ASSET

The following formulas are derived from BTE report (BTE 2001)

The formula is based on an assumption: a durable asset destroyed in a natural disaster is half way through its life; therefore, its value will correspondingly be 50 per cent of its replacement value.

At the end of its economic life it can be expected that a durable asset will be replaced with an equivalent asset. If the asset has a new market value of $K and a life of m years, then at the time of replacement, the present value of the investment outlay is shown in equation A.

$$P_1 = K \frac{(1 + r)^m}{(1 + r)^m - 1} \qquad \text{Equation A}$$

Where r = discount rate

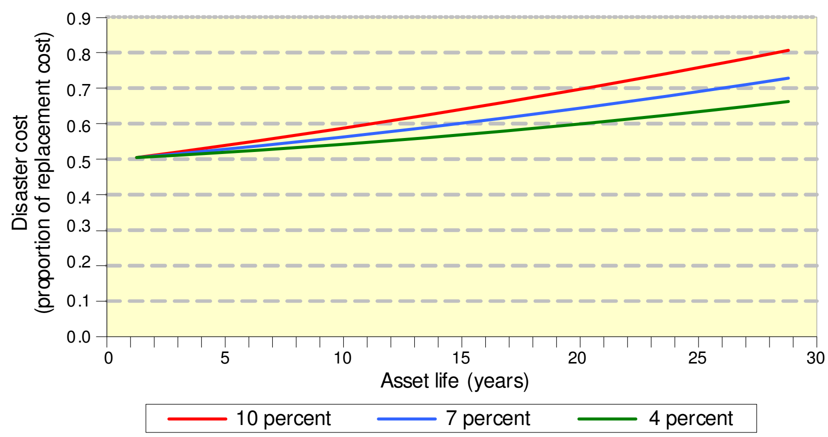


Figure: B.1: Asset loss as a proportion of new market value
Source BTE 2001

Equation A is based on the assumption that the asset will continue to be replaced by a new one at intervals of m years. The effect of the disaster is to bring forward the future investment stream by $m/2$ years. Therefore, the present value of the capital outlay with no disaster (P2) is given by equation B.

$$P_2 = P_1 \frac{1}{(1 + r)^{m/2}} \qquad \text{Equation B}$$

The loss resulting from the disaster is then given by P1–P2.

Generally, the value of the loss is more than 50 percent of the replacement value of the asset. The value increases with the discount rate and the life of the asset (figure B.1)

APPENDIX C: RMSE

The ***root mean square error (RMSE)***) is used to measure the differences between values predicted by a model and the values actually observed from the thing being modelled or estimated. RMSE is a good measure of accuracy.

The RMSE is calculated with

$$\textbf{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(x_{1,i} - x_{2,i})^2}{n}}.$$

Where:

n = number of the incidents (i.e. total number of properties)

x_1 = value predicted from study

x_2 = value actually observed or derived from other model

i = identifier (property id)

APPENDIX D: ATTRIBUTE TABLE OF PROPERTY SHAPE FILE

Building inventory														Adopting stage-damage curves	Measuring damage					
Prop_ID	BF_Area	No_Storey	Blg_Age	BO_Class	Roof_Type	Wall_Type	Inc_Group	Blg_Cost	Blg_Val	Depre_Per	Depre_Val	Blg_Ec_Val	Cnt_Val	DmgCrv_Use	Flood_Dpth	SDmg_Per	SDmg_Doll	CDmg_Per	CDmg_Doll	TDmg_Doll
11	113.01	1	31	RES1	Fibro	Timber	AVERAGE	792.25	89530.95	0.30	26859.29	62671.67	26144.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
177	165.57	1	36	RES1	Metal	Double brick	AVERAGE	875.73	144996.99	0.35	50748.95	94248.05	32314.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
10	135.14	1	36	RES1	Tiles	Fibro	AVERAGE	802.86	108500.33	0.35	37975.12	70525.22	29625.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
181	132.46	1	31	RES1	Metal	Brick veneer	AVERAGE	884.43	117149.23	0.30	35144.77	82004.46	29451.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
22	101.87	1	31	RES1	Metal	Brick veneer	AVERAGE	884.43	90098.09	0.30	27029.43	63068.66	29451.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
13	176.71	1	31	RES1	Tiles	Brick veneer	AVERAGE	877.76	155108.22	0.30	46532.47	108575.75	38182.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
12	187.01	1	36	RES1	Metal	Brick veneer	AVERAGE	872.83	163224.93	0.35	57128.73	106096.20	33255.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
186	210.73	1	31	RES1	Metal	Brick veneer	AVERAGE	883.70	186222.50	0.30	55866.75	130355.75	29692.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
178	167.62	1	31	RES1	Metal	Double brick	AVERAGE	867.75	145456.51	0.30	43636.95	101819.56	34883.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
182	156.67	1	31	RES1	Tiles	Brick veneer	AVERAGE	903.24	141507.89	0.30	42452.37	99055.52	30349.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
183	137.22	1	26	RES1	Tiles	Timber	AVERAGE	789.99	108405.49	0.25	27101.37	81304.11	33416.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
184	193.68	1	31	RES1	Tiles	Brick veneer	AVERAGE	889.34	172245.58	0.30	51673.67	120571.90	34684.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
147	127.93	1	41	RES1	Metal	Fibro	AVERAGE	772.97	98886.72	0.40	39554.69	59332.03	32233.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
141	87.55	1	26	RES1	Metal	Brick veneer	AVERAGE	853.25	74700.17	0.25	18675.04	56025.13	39420.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
96	112.28	1	76	RES1	Tiles	Brick veneer	AVERAGE	882.39	99073.26	0.50	49536.63	49536.63	36796.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
95	112.89	1	71	RES1	Metal	Brick veneer	AVERAGE	867.03	97882.63	0.50	48941.31	48941.31	35114.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
128	177.21	1	7	RES1	Tiles	Brick veneer	AVERAGE	844.56	149663.42	0.06	8979.81	140683.62	47633.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
53	158.66	1	31	RES1	Metal	Timber	AVERAGE	772.30	122533.37	0.30	36760.01	85773.36	32437.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
31	188.41	2	31	RES1	Metal	Fibro	AVERAGE	772.97	145635.71	0.30	43690.71	101945.00	32233.00	RES1-2	0.00	0.00	0.00	0.00	0.00	0.00
52	217.82	1	36	RES1	Tiles	Timber	QUALITY	791.42	172387.31	0.28	48268.45	124118.86	44003.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
86	160.26	1	26	RES1	Tiles	Double brick	AVERAGE	900.92	144380.59	0.25	36095.15	108285.44	31082.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00

Building inventory														Adopting stage-damage curves	Measuring damage					
Prop_ID	**BF_Area**	**No_Storey**	**Blg_Age**	**BO_Class**	**Roof_Type**	**Wall_Type**	**Inc_Group**	**Blg_Cost**	**Blg_Val**	**Depre_Per**	**Depre_Val**	**Blg_Ec_Val**	**Cnt_Val**	**DmgCrv_Use**	**Flood_Dpth**	**SDmg_Per**	**SDmg_Doll**	**CDmg_Per**	**CDmg_Doll**	**TDmg_Doll**
30	350.80	2	6	RES3B	Metal	Timber	AVERAGE	744.60	261205.59	0.06	15672.34	245533.26	26806.00	RES3A-C	0.00	0.00	0.00	0.00	0.00	0.00
28	400.33	2	1	RES1	Metal	Timber	AVERAGE	763.66	305714.41	0.00	0.00	305714.41	35052.00	RES1-2	0.00	0.00	0.00	0.00	0.00	0.00
29	522.98	2	1	RES3B	Metal	Timber	AVERAGE	683.40	357406.53	0.00	0.00	357406.53	49205.00	RES3A-C	0.00	0.00	0.00	0.00	0.00	0.00
136	177.60	1	26	RES1	Tiles	Timber	AVERAGE	794.99	141194.04	0.25	35298.51	105895.53	31959.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
135	219.40	1	31	RES1	Metal	Brick veneer	AVERAGE	870.65	191017.26	0.30	57305.18	133712.08	33955.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
129	179.40	1	26	RES1	Metal	Timber	AVERAGE	776.96	139386.03	0.25	34846.51	104539.52	31000.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
83	196.21	1	31	RES1	Metal	Timber	AVERAGE	778.29	152709.37	0.30	45812.81	106896.56	30586.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
80	237.31	1	31	RES3B	Metal	Fibro	AVERAGE	627.30	148862.69	0.30	44658.81	104203.88	67748.00	RES3A-C	0.00	0.00	0.00	0.00	0.00	0.00
82	137.91	1	31	RES1	Tiles	Brick veneer	AVERAGE	880.85	121480.48	0.30	36444.14	85036.33	37260.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
81	169.85	1	31	RES1	Tiles	Timber	AVERAGE	782.84	132966.49	0.30	39889.95	93076.54	35462.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
85	142.47	1	46	RES1	Tiles	Timber	AVERAGE	782.84	111533.75	0.45	50190.19	61343.56	35462.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
191	139.67	1	21	RES1	Tiles	Timber	AVERAGE	798.57	111534.53	0.20	22306.91	89227.63	30904.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
114	270.69	2	31	RES1	Tiles	Timber	QUALITY	802.86	217325.48	0.24	52158.12	165167.37	39500.00	RES1-2	0.62	0.25	41143.19	0.61	23976.50	65119.69
14	314.28	1	21	RES1	Tiles	Timber	AVERAGE	640.55	201311.65	0.20	40262.33	161049.32	96082.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
115	246.51	2	36	RES1	Tiles	Double brick	QUALITY	873.90	215428.53	0.28	60319.99	155108.54	52434.00	RES1-2	0.00	0.00	0.00	0.00	0.00	0.00
116	136.22	1	71	RES1	Tiles	Timber	AVERAGE	794.99	108290.95	0.50	54145.48	54145.48	31959.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
2	120.46	1	26	RES3A	Tiles	Double brick	AVERAGE	765.94	92268.47	0.25	23067.12	69201.35	55148.00	RES3A-C	0.00	0.00	0.00	0.00	0.00	0.00
84	142.77	1	46	RES1	Tiles	Timber	AVERAGE	807.15	115236.05	0.45	51856.22	63379.83	28331.00	RES1-1	0.67	0.25	15787.91	0.61	17196.92	32984.83
51	96.52	1	71	RES1	Metal	Timber	AVERAGE	767.65	74092.30	0.50	37046.15	37046.15	33853.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
113	182.73	1	31	RES1	Tiles	Brick veneer	AVERAGE	881.62	161097.75	0.30	48329.33	112768.43	37028.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
112	129.44	1	71	RES1	Tiles	Double brick	AVERAGE	883.16	114316.32	0.50	57158.16	57158.16	36563.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
1	152.90	1	31	RES1	Tiles	Double brick	AVERAGE	872.36	133379.42	0.30	40013.83	93365.59	39779.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
106	169.34	1	31	RES1	Tiles	Timber	AVERAGE	794.99	134625.19	0.30	40387.56	94237.63	31959.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
4	150.91	1	36	RES1	Tiles	Timber	AVERAGE	793.56	119759.61	0.35	41915.86	77843.74	32377.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
108	133.63	1	71	RES1	Metal	Timber	AVERAGE	761.66	101780.95	0.50	50890.48	50890.48	35646.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
5	254.12	1	31	RES1	Tiles	Timber	AVERAGE	787.84	200202.78	0.30	60060.83	140141.94	34035.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
38	146.62	1	46	RES1	Tiles	Brick veneer	AVERAGE	880.85	129153.92	0.45	58119.27	71034.66	37260.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
109	131.14	1	46	RES1	Tiles	Brick veneer	AVERAGE	870.04	114099.71	0.45	51344.87	62754.84	40457.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00

Building inventory														**Adopting stage-damage curves**	**Measuring damage**					
Prop_ID	**BF_Area**	**No_Storey**	**Blg_Age**	**BO_Class**	**Roof_Type**	**Wall_Type**	**Inc_Group**	**Blg_Cost**	**Blg_Val**	**Depre_Per**	**Depre_Val**	**Blg_Ec_Val**	**Cnt_Val**	**DmgCrv_Use**	**Flood_Dpth**	**SDmg_Per**	**SDmg_Doll**	**CDmg_Per**	**CDmg_Doll**	**TDmg_Doll**
103	245.09	1	31	RES1	Tiles	Double brick	AVERAGE	890.88	218342.65	0.30	65502.79	152839.85	34210.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
111	197.36	1	71	RES1	Tiles	Double brick	AVERAGE	871.58	172014.68	0.50	86007.34	86007.34	40006.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
50	198.92	1	71	RES1	Tiles	Brick veneer	AVERAGE	880.85	175222.14	0.50	87611.07	87611.07	37260.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
110	133.30	1	71	RES1	Metal	Timber	AVERAGE	765.65	102059.09	0.50	51029.54	51029.54	34454.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
107	210.66	1	31	RES1	Metal	Timber	AVERAGE	776.29	163535.34	0.30	49060.60	114474.74	31207.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
3	111.96	1	26	RES1	Tiles	Double brick	AVERAGE	882.39	98793.60	0.25	24698.40	74095.20	36796.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
105	161.56	1	26	RES1	Tiles	Timber	AVERAGE	800.00	129248.62	0.25	32312.16	96936.47	30480.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
6	146.93	1	31	RES1	Tiles	Timber	AVERAGE	795.71	116910.31	0.30	35073.09	81837.22	31749.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
56	151.52	1.	71	RES1	Metal	Timber	AVERAGE	753.02	114096.72	0.50	57048.36	57048.36	38178.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
117	226.14	1	61	RES1	Metal	Timber	AVERAGE	774.96	175251.02	0.50	87625.51	87625.51	31618.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
104	184.11	1	31	RES1	Tiles	Brick veneer	AVERAGE	887.02	163308.84	0.30	48992.65	114316.19	35392.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
26	1936.66	1	6	RES3C	Tiles	Timber	AVERAGE	640.55	1240529.93	0.06	74431.80	1166098.14	96082.00	RES3A-C	0.00	0.00	0.00	0.00	0.00	0.00
140	2271.83	1	26	RES3C	Tiles	Double brick	AVERAGE	719.50	1634583.37	0.25	408645.84	1225937.53	107925.00	RES3A-C	0.00	0.00	0.00	0.00	0.00	0.00
60	372.18	1	21	RES1	Tiles	Brick veneer	AVERAGE	873.90	325245.66	0.20	65049.13	260196.53	39326.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
64	357.12	1	21	RES3B	Metal	Double brick	AVERAGE	704.95	251750.06	0.20	50350.01	201400.05	126891.00	RES3A-C	0.00	0.00	0.00	0.00	0.00	0.00
72	250.98	1	71	RES3B	Metal	Double brick	AVERAGE	704.95	176927.87	0.50	88463.94	88463.94	126891.00	RES3A-C	0.00	0.00	0.00	0.00	0.00	0.00
65	22.57	1	1	RES1	Tiles	Double brick	AVERAGE	861.55	19449.04	0.00	0.00	19449.04	42905.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
62	301.18	1	71	RES1	Tiles	Timber	AVERAGE	770.68	232114.52	0.50	116057.26	116057.26	38842.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
63	172.82	1	71	RES1	Tiles	Double brick	AVERAGE	860.78	148755.63	0.50	74377.81	74377.81	43125.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
145	138.34	1	36	RES1	Tiles	Brick veneer	AVERAGE	904.01	125061.19	0.35	43771.42	81289.77	30104.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
7	231.08	1	26	RES1	Tiles	Brick veneer	AVERAGE	872.36	201580.12	0.25	50395.03	151185.09	39779.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
146	319.45	2	1	RES1	Tiles	Brick veneer	AVERAGE	900.92	287795.71	0.00	0.00	287795.71	31082.00	RES1-2	0.00	0.00	0.00	0.00	0.00	0.00
137	121.28	1	36	RES1	Tiles	Brick veneer	AVERAGE	909.41	110297.79	0.35	38604.23	71693.56	28374.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
176	576.74	2	3	RES1	Tiles	Brick veneer	AVERAGE	912.50	526279.68	0.03	15788.39	510491.29	24638.00	RES1-2	0.00	0.00	0.00	0.00	0.00	0.00
124	159.39	1	31	RES1	Tiles	Brick veneer	AVERAGE	907.10	144583.92	0.30	43375.17	101208.74	29118.00	RES1-1	0.74	0.25	25211.10	0.61	17674.63	42885.72
35	145.81	1	31	RES1	Tiles	Brick veneer	AVERAGE	904.01	131812.78	0.30	39543.83	92268.95	30104.00	RES1-1	0.06	0.18	16608.41	0.00	0.00	16608.41
121	141.13	1	46	RES1	Tiles	Brick veneer	AVERAGE	882.39	124531.03	0.45	56038.97	68492.07	36796.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00

Building inventory														Adopting stage-damage curves	Measuring damage					
Prop_ID	**BF_Area**	**No_Storey**	**Blg_Age**	**BO_Class**	**Roof_Type**	**Wall_Type**	**Inc_Group**	**Blg_Cost**	**Blg_Val**	**Depre_Per**	**Depre_Val**	**Blg_Ec_Val**	**Cnt_Val**	**DmgCrv_Use**	**Flood_Dpth**	**SDmg_Per**	**SDmg_Doll**	**CDmg_Per**	**CDmg_Doll**	**TDmg_Doll**
36	175.66	1	31	RES1	Tiles	Brick veneer	AVERAGE	903.24	158661.36	0.30	47598.41	111062.95	30349.00	RES1-1	0.10	0.18	19991.33	0.00	0.00	19991.33
132	90.37	1	61	RES1	Tiles	Brick veneer	AVERAGE	903.24	81628.08	0.50	40814.04	40814.04	30349.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
119	118.74	1	36	RES1	Tiles	Brick veneer	AVERAGE	882.39	104778.74	0.35	36672.56	68106.18	36796.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
58	147.68	1	1	RES1	Tiles	Brick veneer	AVERAGE	858.46	126778.22	0.00	0.00	126778.22	43781.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
61	349.72	2	26	RES1	Tiles	Brick veneer	AVERAGE	860.00	300763.48	0.25	75190.87	225572.61	43344.00	RES1-2	0.00	0.00	0.00	0.00	0.00	0.00
59	161.03	1	61	RES1	Tiles	Brick veneer	AVERAGE	862.32	138860.40	0.50	69430.20	69430.20	42685.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
202	200.06	1	31	RES1	Tiles	Brick veneer	AVERAGE	883.94	176838.00	0.30	53051.40	123786.60	36330.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
198	251.70	1	71	RES3B	Tiles	Brick veneer	AVERAGE	825.82	207855.15	0.50	103927.58	103927.58	29729.00	RES3A-C	0.00	0.00	0.00	0.00	0.00	0.00
196	195.20	1	21	RES1	Tiles	Brick veneer	AVERAGE	719.50	140445.33	0.20	28089.07	112356.26	107925.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
197	437.54	1	36	RES3B	Tiles	Brick veneer	AVERAGE	825.82	361327.92	0.35	126464.77	234863.15	29729.00	RES3A-C	0.00	0.00	0.00	0.00	0.00	0.00
18	234.50	1	26	RES3B	Tiles	Brick veneer	AVERAGE	711.05	166742.88	0.25	41685.72	125057.16	102391.00	RES3A-C	0.00	0.00	0.00	0.00	0.00	0.00
193	304.60	1	26	RES3B	Tiles	Brick veneer	AVERAGE	711.05	216583.57	0.25	54145.89	162437.68	74660.00	RES3A-C	0.00	0.00	0.00	0.00	0.00	0.00
187	304.13	1	26	RES1	Tiles	Brick veneer	AVERAGE	719.50	218818.94	0.25	54704.74	164114.21	107925.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
139	232.33	1	26	RES1	Tiles	Brick veneer	AVERAGE	719.50	167159.46	0.25	41789.87	125369.60	107925.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
142	1147.45	1	16	RES3C	Tiles	Brick veneer	AVERAGE	825.82	947583.61	0.15	142137.54	805446.07	29729.00	RES3A-C	0.00	0.00	0.00	0.00	0.00	0.00
173	387.83	1	11	RES1	Tiles	Brick veneer	AVERAGE	719.50	279045.90	0.10	27904.59	251141.31	107925.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
68	146.61	1	26	RES1	Tiles	Brick veneer	AVERAGE	890.88	130613.51	0.25	32653.38	97960.13	34210.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
157	170.51	1	31	RES1	Tiles	Brick veneer	AVERAGE	906.32	154537.27	0.30	46361.18	108176.09	29365.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
188	166.28	1	41	RES1	Tiles	Brick veneer	AVERAGE	719.50	119637.75	0.40	47855.10	71782.65	107925.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
158	178.60	1	31	RES1	Tiles	Brick veneer	AVERAGE	907.10	162005.18	0.30	48601.55	113403.62	29118.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
190	297.88	1	41	RES1	Tiles	Brick veneer	AVERAGE	719.50	214323.28	0.40	85729.31	128593.97	107925.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
92	190.47	1	26	RES1	Tiles	Brick veneer	AVERAGE	907.10	172775.44	0.25	43193.86	129581.58	29118.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
70	227.96	1	36	RES1	Tiles	Brick veneer	AVERAGE	869.27	198155.46	0.35	69354.41	128801.05	40682.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
55	207.08	1	31	RES1	Tiles	Brick veneer	QUALITY	876.99	181605.67	0.24	43585.36	138020.31	51216.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
133	134.88	1	31	RES1	Tiles	Brick veneer	AVERAGE	908.64	122559.90	0.30	36767.97	85791.93	28622.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
153	342.87	2	21	RES1	Tiles	Brick veneer	AVERAGE	875.44	300166.87	0.20	60033.37	240133.49	38870.00	RES1-2	0.00	0.00	0.00	0.00	0.00	0.00
134	196.33	1	36	RES1	Tiles	Brick	AVERAGE	891.66	175061.74	0.35	61271.61	113790.13	33972.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00

Building inventory														Adopting stage-damage curves	Measuring damage					
Prop_ID	BF_Area	No_Storey	Blg_Age	BO_Class	Roof_Type	Wall_Type	Inc_Group	Blg_Cost	Blg_Val	Depre_Per	Depre_Val	Blg_Ec_Val	Cnt_Val	DmgCrv_Use	Flood_Dpth	SDmg_Per	SDmg_Doll	CDmg_Per	CDmg_Doll	TDmg_Doll
						veneer														
89	186.03	1	31	RES1	Tiles	Brick veneer	AVERAGE	893.97	166302.59	0.30	49890.78	116411.82	33256.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
16	301.76	1	41	RES1	Tiles	Brick veneer	AVERAGE	719.50	217112.74	0.40	86845.09	130267.64	107925.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
171	319.54	2	41	RES1	Tiles	Brick veneer	AVERAGE	719.50	229911.80	0.40	91964.72	137947.08	107925.00	RES1-2	0.00	0.00	0.00	0.00	0.00	0.00
165	263.34	1	51	RES3B	Tiles	Brick veneer	AVERAGE	825.82	217468.71	0.50	108734.36	108734.36	29729.00	RES3A-C	0.00	0.00	0.00	0.00	0.00	0.00
194	504.79	2	36	RES3B	Tiles	Brick veneer	AVERAGE	825.82	416864.35	0.35	145902.52	270961.83	29729.00	RES3A-C	0.00	0.00	0.00	0.00	0.00	0.00
166	268.81	1	26	RES1	Tiles	Brick veneer	AVERAGE	801.33	215406.20	0.25	53851.55	161554.65	58658.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
15	240.00	1	26	RES1	Tiles	Brick veneer	AVERAGE	835.30	200468.82	0.25	50117.21	150351.62	50118.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
201	202.91	1	45	RES3A	Tiles	Brick veneer	AVERAGE	825.82	167564.13	0.40	67025.65	100538.48	29729.00	RES3A-C	0.00	0.00	0.00	0.00	0.00	0.00
20	183.27	1	31	RES1	Tiles	Brick veneer	AVERAGE	843.79	154645.31	0.30	46393.59	108251.71	47843.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
195	424.29	1	26	RES3B	Tiles	Brick veneer	AVERAGE	825.82	350384.65	0.25	87596.16	262788.49	29729.00	RES3A-C	0.00	0.00	0.00	0.00	0.00	0.00
17	186.59	1	21	RES1	Tiles	Brick veneer	AVERAGE	850.74	158737.11	0.20	31747.42	126989.69	45940.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
163	349.18	1	36	RES1	Tiles	Brick veneer	AVERAGE	817.54	285472.11	0.35	99915.24	185556.87	54694.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
199	244.08	1	41	RES1	Tiles	Brick veneer	AVERAGE	851.51	207840.32	0.40	83136.13	124704.19	45726.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
19	373.58	1	61	RES3B	Tiles	Brick veneer	AVERAGE	825.82	308508.24	0.50	154254.12	154254.12	29729.00	RES3A-C	0.00	0.00	0.00	0.00	0.00	0.00
161	656.79	1	40	RES3B	Tiles	Brick veneer	AVERAGE	825.82	542389.30	0.35	189836.25	352553.04	29729.00	RES3A-C	0.00	0.00	0.00	0.00	0.00	0.00
180	248.35	1	71	RES1	Tiles	Brick veneer	AVERAGE	794.38	197287.06	0.50	98643.53	98643.53	60294.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
164	546.19	1	36	RES3B	Tiles	Brick veneer	AVERAGE	825.82	451053.68	0.35	157868.79	293184.89	29729.00	RES3A-C	0.00	0.00	0.00	0.00	0.00	0.00
66	296.40	1	21	RES1	Tiles	Brick veneer	AVERAGE	796.70	236143.07	0.20	47228.61	188914.45	59752.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
189	263.55	1	41	RES1	Tiles	Brick veneer	AVERAGE	840.70	221567.45	0.40	88626.98	132940.47	48677.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
204	231.55	1	31	RES1	Tiles	Brick veneer	AVERAGE	869.27	201280.38	0.30	60384.11	140896.27	40682.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
200	136.09	1	71	RES3A	Tiles	Brick veneer	AVERAGE	825.82	112386.23	0.50	56193.11	56193.11	29729.00	RES3A-C	0.00	0.00	0.00	0.00	0.00	0.00
21	149.37	1	61	RES1	Tiles	Brick veneer	AVERAGE	832.98	124426.28	0.50	62213.14	62213.14	50729.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
192	309.49	1	26	RES3B	Tiles	Brick veneer	AVERAGE	765.94	237053.97	0.25	59263.49	177790.48	55148.00	RES3A-C	0.00	0.00	0.00	0.00	0.00	0.00
170	495.96	2	26	RES1	Tiles	Brick veneer	AVERAGE	719.50	356840.62	0.25	89210.15	267630.46	107925.00	RES1-2	0.00	0.00	0.00	0.00	0.00	0.00
24	186.50	1	71	RES1	Tiles	Brick veneer	AVERAGE	782.80	145991.50	0.50	72995.75	72995.75	62937.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
162	199.06	1	71	RES1	Tiles	Brick veneer	AVERAGE	833.76	165968.80	0.50	82984.40	82984.40	50526.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00

Building inventory														Adopting stage-damage curves	Measuring damage					
Prop_ID	BF_Area	No_Storey	Blg_Age	BO_Class	Roof_Type	Wall_Type	Inc_Group	Blg_Cost	Blg_Val	Depre_Per	Depre_Val	Blg_Ec_Val	Cnt_Val	DmgCrv_Use	Flood_Dpth	SDmg_Per	SDmg_Doll	CDmg_Per	CDmg_Doll	TDmg_Doll
71	168.41	1	31	RES1	Tiles	Brick veneer	AVERAGE	887.02	149384.36	0.30	44815.31	104569.05	35392.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
203	232.67	1	26	RES1	Tiles	Brick veneer	AVERAGE	823.72	191656.48	0.25	47914.12	143742.36	53130.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
167	386.54	1	36	RES1	Tiles	Brick veneer	AVERAGE	719.50	278118.22	0.35	97341.38	180776.84	107925.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
175	362.16	2	21	RES3A	Tiles	Brick veneer	AVERAGE	825.82	299077.07	0.20	59815.41	239261.65	29729.00	RES3A-C	0.00	0.00	0.00	0.00	0.00	0.00
79	400.04	1	71	RES3B	Tiles	Brick veneer	AVERAGE	825.82	330364.47	0.50	165182.23	165182.23	29729.00	RES3A-C	0.00	0.00	0.00	0.00	0.00	0.00
78	510.60	2	36	RES3B	Tiles	Double brick	AVERAGE	854.00	436050.13	0.35	152617.54	283432.58	338184.00	RES3A-C	0.00	0.00	0.00	0.00	0.00	0.00
149	107.75	1	71	RES1	Tiles	Brick veneer	QUALITY	889.34	95827.77	0.40	38331.11	57496.66	46246.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
148	102.40	2	11	RES1	Tiles	Brick veneer	QUALITY	912.50	93444.26	0.08	7475.54	85968.72	23725.00	RES1-2	0.00	0.00	0.00	0.00	0.00	0.00
160	198.83	2	26	RES3B	Tiles	Brick veneer	QUALITY	711.05	141380.46	0.18	25448.48	115931.98	102391.00	RES3A-C	0.00	0.00	0.00	0.00	0.00	0.00
155	167.78	1	31	RES1	Tiles	Brick veneer	AVERAGE	719.50	120718.47	0.30	36215.54	84502.93	107925.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
69	169.16	1	26	RES1	Tiles	Brick veneer	AVERAGE	873.90	147831.06	0.25	36957.77	110873.30	39326.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
168	211.02	1	21	RES1	Tiles	Brick veneer	AVERAGE	719.50	151828.24	0.20	30365.65	121462.59	107925.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
90	409.12	2	26	RES1	Tiles	Brick veneer	AVERAGE	906.32	370796.40	0.25	92699.10	278097.30	29365.00	RES1-2	0.00	0.00	0.00	0.00	0.00	0.00
91	200.59	1	26	RES1	Tiles	Brick veneer	AVERAGE	907.87	182105.61	0.25	45526.40	136579.20	28870.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
154	142.10	1	31	RES1	Tiles	Brick veneer	AVERAGE	804.42	114304.96	0.30	34291.49	80013.47	57918.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
57	172.44	1	31	RES1	Tiles	Brick veneer	QUALITY	855.37	147497.00	0.24	35399.28	112097.72	59534.00	RES1-1	0.10	0.18	20177.59	0.00	0.00	20177.59
27	183.35	1	21	RES1	Tiles	Brick veneer	AVERAGE	910.18	166885.29	0.20	33377.06	133508.24	28125.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
159	129.03	1	71	RES1	Tiles	Brick veneer	QUALITY	889.34	114753.04	0.40	45901.21	68851.82	46246.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
77	128.16	1	31	RES1	Tiles	Brick veneer	AVERAGE	893.20	114471.05	0.30	34341.31	80129.73	33495.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
73	152.46	1	71	RES1	Tiles	Brick veneer	AVERAGE	890.11	135703.96	0.50	67851.98	67851.98	34447.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
144	170.62	1	36	RES1	Tiles	Brick veneer	AVERAGE	903.24	154110.90	0.35	53938.82	100172.09	30349.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
8	154.72	1	36	RES1	Tiles	Brick veneer	AVERAGE	903.24	139747.02	0.35	48911.46	90835.56	30349.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
9	222.53	1	31	RES1	Tiles	Brick veneer	AVERAGE	893.97	198934.09	0.30	59680.23	139253.86	33256.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
25	624.74	1	9	RES3B	Tiles	Brick veneer	AVERAGE	907.87	567183.76	0.06	34031.03	533152.73	28870.00	RES3A-C	0.00	0.00	0.00	0.00	0.00	0.00
143	139.61	1	36	RES1	Tiles	Brick veneer	AVERAGE	907.87	126746.74	0.35	44361.36	82385.38	28870.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
120	227.47	1	46	RES1	Tiles	Brick veneer	AVERAGE	881.62	200545.01	0.45	90245.26	110299.76	37028.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
33	159.17	1	46	RES1	Tiles	Brick	AVERAGE	899.38	143150.08	0.45	64417.54	78732.54	31568.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00

Building inventory														**Adopting stage-damage curves**	**Measuring damage**					
Prop_ID	**BF_Area**	**No_Storey**	**Blg_Age**	**BO_Class**	**Roof_Type**	**Wall_Type**	**Inc_Group**	**Blg_Cost**	**Blg_Val**	**Depre_Per**	**Depre_Val**	**Blg_Ec_Val**	**Cnt_Val**	**DmgCrv_Use**	**Flood_Dpth**	**SDmg_Per**	**SDmg_Doll**	**CDmg_Per**	**CDmg_Doll**	**TDmg_Doll**
						veneer														
131	121.71	1	71	RES1	Tiles	Brick veneer	AVERAGE	880.85	107207.09	0.50	53603.55	53603.55	37260.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
34	258.16	2	31	RES1	Tiles	Brick veneer	AVERAGE	890.11	229793.38	0.30	68938.02	160855.37	34447.00	RES1-2	0.69	0.25	40069.07	0.61	20909.33	60978.40
123	143.46	1	71	RES1	Tiles	Brick veneer	AVERAGE	907.10	130132.49	0.50	65066.25	65066.25	29118.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
118	145.11	1	71	RES1	Tiles	Brick veneer	AVERAGE	891.66	129389.63	0.50	64694.82	64694.82	33972.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
122	137.36	1	26	RES1	Tiles	Brick veneer	AVERAGE	882.39	121207.68	0.25	30301.92	90905.76	36796.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
32	110.65	1	51	RES1	Tiles	Brick veneer	AVERAGE	904.01	100030.96	0.50	50015.48	50015.48	30104.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
130	169.61	1	71	RES1	Tiles	Brick veneer	AVERAGE	891.66	151230.41	0.50	75615.20	75615.20	33972.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
39	150.95	1	41	RES1	Tiles	Brick veneer	AVERAGE	898.60	135645.43	0.40	54258.17	81387.26	31810.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
37	29.13	1	31	RES1	Tiles	Brick veneer	AVERAGE	903.24	26309.69	0.30	7892.91	18416.78	30349.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
87	170.93	1	31	RES1	Tiles	Brick veneer	AVERAGE	907.87	155182.52	0.30	46554.75	108627.76	28870.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
88	124.05	1	21	RES1	Tiles	Brick veneer	AVERAGE	870.81	108024.47	0.20	21604.89	86419.58	40232.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
152	560.16	1	26	RES3C	Tiles	Brick veneer	AVERAGE	825.82	462594.71	0.25	115648.68	346946.03	29729.00	RES3A-C	0.00	0.00	0.00	0.00	0.00	0.00
156	1503.63	1	21	RES3C	Tiles	Concrete frame	AVERAGE	854.00	1284098.06	0.20	256819.61	1027278.45	491904.00	RES3A-C	0.00	0.00	0.00	0.00	0.00	0.00
151	128.60	1	41	RES1	Tiles	Brick veneer	AVERAGE	876.99	112782.00	0.40	45112.80	67669.20	38412.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
150	108.96	1	31	RES1	Tiles	Brick veneer	AVERAGE	875.44	95387.70	0.30	28616.31	66771.39	38870.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
127	131.66	1	71	RES1	Tiles	Brick veneer	AVERAGE	815.23	107331.64	0.50	53665.82	53665.82	55273.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
101	120.11	1	71	RES3A	Tiles	Brick veneer	AVERAGE	825.82	99191.38	0.50	49595.69	49595.69	29729.00	RES3A-C	0.00	0.00	0.00	0.00	0.00	0.00
48	180.30	1	71	RES1	Tiles	Brick veneer	AVERAGE	861.55	155337.35	0.50	77668.67	77668.67	42905.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
47	350.69	2	21	RES1	Tiles	Brick veneer	AVERAGE	890.11	312156.81	0.20	62431.36	249725.45	34447.00	RES1-2	0.00	0.00	0.00	0.00	0.00	0.00
40	193.80	1	41	RES1	Tiles	Brick veneer	AVERAGE	839.16	162628.79	0.40	65051.51	97577.27	49091.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
49	167.93	1	71	RES1	Tiles	Brick veneer	AVERAGE	844.56	141828.01	0.50	70914.01	70914.01	47633.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
97	221.07	1	16	RES1	Tiles	Brick veneer	AVERAGE	816.00	180394.05	0.15	27059.11	153334.94	55080.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
126	261.37	1	26	RES1	Tiles	Brick veneer	AVERAGE	903.24	236078.24	0.25	59019.56	177058.68	30349.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
93	1027.34	1	26	RES3C	Tiles	Brick veneer	AVERAGE	817.54	839896.83	0.25	209974.21	629922.62	54694.00	RES3A-C	0.00	0.00	0.00	0.00	0.00	0.00
102	116.12	1	36	RES1	Tiles	Brick veneer	AVERAGE	817.54	94935.94	0.35	33227.58	61708.36	54694.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
98	216.43	1	26	RES1	Tiles	Brick veneer	AVERAGE	819.09	177278.00	0.25	44319.50	132958.50	54305.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00

Building inventory														**Adopting stage-damage curves**	**Measuring damage**					
Prop_ID	**BF_Area**	**No_Storey**	**Blg_Age**	**BO_Class**	**Roof_Type**	**Wall_Type**	**Inc_Group**	**Blg_Cost**	**Blg_Val**	**Depre_Per**	**Depre_Val**	**Blg_Ec_Val**	**Cnt_Val**	**DmgCrv_Use**	**Flood_Dpth**	**SDmg_Per**	**SDmg_Doll**	**CDmg_Per**	**CDmg_Doll**	**TDmg_Doll**
99	278.60	1	41	RES1	Tiles	Brick veneer	AVERAGE	816.00	227337.48	0.40	90934.99	136402.49	55080.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
43	300.69	2	36	RES1	Tiles	Brick veneer	AVERAGE	841.48	253020.93	0.35	88557.33	164463.61	48469.00	RES1-2	0.00	0.00	0.00	0.00	0.00	0.00
45	242.41	1	31	RES1	Tiles	Brick veneer	AVERAGE	849.20	205856.07	0.30	61756.82	144099.25	46366.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
100	175.47	1	46	RES1	Tiles	Brick veneer	AVERAGE	816.00	143181.76	0.45	64431.79	78749.97	55080.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
42	334.18	1	31	RES1	Tiles	Brick veneer	AVERAGE	843.79	281980.78	0.30	84594.23	197386.55	47843.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
125	134.55	1	46	RES1	Tiles	Brick veneer	AVERAGE	819.09	110207.72	0.45	49593.47	60614.24	54305.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
41	138.91	1	41	RES1	Tiles	Brick veneer	AVERAGE	801.33	111314.49	0.40	44525.80	66788.69	58658.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
46	188.56	1	31	RES1	Tiles	Brick veneer	AVERAGE	837.62	157938.43	0.30	47381.53	110556.90	49503.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00
44	147.81	1	41	RES1	Tiles	Brick veneer	AVERAGE	841.48	124380.46	0.40	49752.18	74628.27	48469.00	RES1-1	0.00	0.00	0.00	0.00	0.00	0.00